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Phase II, ~~Report~~

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FOREWORD

This Phase II report was prepared for the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama, by the Orlando Division of the Martin-Marietta Corporation in accordance with Exhibit A of Contract No. NAS 8-20131, dated 5 April 1965.

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SUMMARY

This program is designed to select one or more transparent materials that can be used to standardize infrared emissivity to a high constant value when applied as a coating to electrical/electronic components. Infrared radiation levels of similar electrical/electronic components could then be accurately compared.

In Phase II, 15 commercially available and ten Martin prepared high emissivity conformal coatings were tested for their electrical and physical properties. The 25 coatings were tested in liquid and cured states and consisted of such compounds as epoxy, epoxy-polysulfide, epoxy-silicone, polyurethane, polyimide, acrylic, polycarbonate, and silicone. On the basis of initial screening tests, the ten most promising compounds were selected for more extensive testing.

In all, five different liquid coating tests and 13 different cured coating tests were conducted on each of the ten finalist coatings to determine: 1) various physical and electrical properties, 2) compatibility with materials commonly encountered in electrical/electronic equipment fabrication processes, (soldering fluxes, flux residues, and cleaning solvents), and 3) ability of the coatings to withstand a variety of environments.

With the exception of a few relative weaknesses in the areas of adhesion, water absorption, elevated temperature electrical properties, and outgassing, these ten coatings performed satisfactorily as conformal coatings. However, since the actual use environment was never specified for this study, no one compound was singled out as being superior to the others in respect to all of the properties determined. Rather, the ten finalist coatings were ranked relative to their individual performance on each of the test parameters.

INTRODUCTION

The effort described in this report constitutes the Phase II portion of activities performed under Contract No. NAS 8-20131, dated 5 April 1965. The purpose of this contract is to determine the feasibility of developing a nondestructive testing technique, using infrared (IR) radiation measurement, for detecting incipient failures that are not revealed by present electrical testing methods. Contract performance is divided into three phases.

Phase I involved a comprehensive survey of literature as well as a survey of industrial and government organizations conducting IR measurement programs oriented to electronic component evaluation. The objective was to determine the state-of-the-art relative to IR instrumentation, IR measurement technology, and specific areas of application being investigated. As was anticipated, this survey proved that emissivity correction is a problem of considerable magnitude throughout industry. Results are documented in Martin-Orlando Phase I report OR 6610, "Infrared Testing of Electronic Components," dated June 1965.

Phase II consisted of developing one or more conformal coating materials for standardizing the emissivity of electrical and electronic components to a high constant value while meeting specified mechanical, electrical, and environmental requirements. A prime characteristic of the coating was transparency to permit retention of identification of components.

Phase III, initiated concurrently with Phase II, consists of: 1) establishing a correlation between IR and transistor life expectance, 2) "fingerprinting" and analysis of circuit designs, 3) investigating use of IR for thermally evaluating packaging techniques, 4) preparation of radiometer and associated equipment procurement specifications.

This phase is scheduled for completion during May 1966.

I. EMISSIVITY COATING DEVELOPMENT TEST PLAN

A. BACKGROUND

Infrared (IR) energy is radiated by any object whose temperature is above absolute zero. The amount and spectral characteristics of the energy radiated are dependent upon the absolute temperature of the object and also upon the nature of its surface finish or emissivity. Hence, the emissivity factor of an object is a measure of its radiation and absorbing efficiency. Due to the vast number of surface finish variations existing among electronic components, accurate comparison of IR radiation from different components would be a monumental task. Fortunately, emissivity is a surface property, thus it may be possible to achieve a constant emissivity value by coating all surfaces with a uniform film or coating.

The development of one or more coatings, capable of standardizing the emissivity of electronic components to a high constant value under specified electrical, mechanical, and environmental requirements, was the objective of Phase II.

B. TECHNICAL APPROACH

There is an exact relationship between IR emission and absorption which shows that high emissivity requires a material with low reflectance and high absorption. According to Kirchoff's law, absorptivity is directly proportional to emissivity; therefore, a satisfactory absorber is a desirable emitter. It was this relationship that was used during the initial material selection stage of the coating development, to indicate the relative emissivities of the compound being evaluated.

In organic compounds, each generic type of chemical bonding has characteristic absorption frequencies (bands). The number of these absorption bands increases directly with molecular complexity, with band intensity being dependent upon the dipole moment (the difference in the electronegativity between two atoms).

It was initially decided to include for investigation two types of plastic materials having properties meeting the optical, chemical, and physical requirements for emissivity coatings. These were thermosetting plastics, such as the polyurethanes, silicones, and epoxys, and thermo plastic materials, such as the acrylics and polycarbonates. A coating, previously developed by Martin, which satisfactorily met the transparency and emissivity requirements, was also included in the testing.

C. TESTS

To cover as extensive an area of study as possible, it was planned to review a large number of readily available commercial coating compounds. Those compounds showing potential merit on the basis of vendor data would be selected for screening tests. Those that successfully passed the initial screening tests would then be subjected to further tests to rank them in order of preference for each physical property.

It is realized that there are many more conformal coating type materials commercially available than those included in the test program, and that some of these may have superior characteristics in certain areas. However, within the limitations of the contract it was not possible to evaluate all these compounds at this time.

II. SCREENING TESTS

A total of 15 commercially available compounds and ten Martin prepared compounds were processed through initial screening tests. The test results obtained were indicative of the performance which could be expected of the coatings in actual usage. On the basis of the results of the first nine screening tests, A1 through 5 and B1 through 4, listed and defined in Table I, ten materials were selected for further evaluation. Emissivity was considered the most important parameter in these tests. Tests B5 through B13 list the additional tests to which the ten selected materials were subjected.

Each table of results included herein lists the compounds with respect to their performance in that particular test area, with the 10 finalist coatings being listed first. At the completion of all tests, an overall evaluation of the materials was made.

TABLE I

Screening Tests

Test	Definition (as used in this program)
A. Liquid Properties	
1) Viscosity	Resistance to flow resulting from the combined effects of adhesion and cohesion. (Determined on Brookfield Model RVF Viscometer shown in Figure 1.)
2) Drying Time	The time required for the applied coating to lose its tackiness.
3) Curing Cycle	The time and temperature required for complete cure of the material.
4) Pot Life	The length of time after mixing the constituents of the compound that the material is capable of being applied to printed circuit boards.

TABLE I (Cont)

Test	Definition (as used in this program)
5) Infrared Absorption	The relative absorption of IR radiation in the band from about 4 to 14 microns. (Determined by a Beckman IR-9 Spectrophotometer shown in Figure 2.)
B. Cured Properties	
1) Transparency	Visual examination of thin films of the materials for their transparency.
2) Emissivity Factor	The efficiency of a radiating surface relative to a perfect black body (1.0 factor).
3) Maximum Use Temperature	Maximum continuous service temperature.
4) Flexibility	Visual examination of cast sheet material for its general elastic properties.
5) Adhesion	The force required to strip a 1 in. wide length of canvas bonded to an epoxy glass printed circuit board. (Determined in accordance with ASTM-D 903 on an Instron Testing Machine shown in Figure 3.)
6) Water Absorption	The percent by weight of water absorbed after 24 hours immersion in water at room temperature (per ASTM-D 570).
7) Coefficient of Linear Thermal Expansion	The amount a material changes length with the application of heat. Expressed in inches/inch/degree centigrade. (Determined in accordance with ASTM-D 696 on a Quartz Tube Dilatometer shown in Figure 4.)

TABLE I (Cont)

Test	Definition (as used in this program)
8) Solderability	The ease of repairing a coated soldered joint on a printed circuit board.
9) Chemical Resistance	The effect of various solutions on the coatings.
10) Electrical Properties	
a) Dielectric Strength	Voltage required to break down the insulation resistance of the coating. Expressed in volts per mil. (Performed according to ASTM-D 115 on a Davenport High Potential Tester, Model XVA, 100-50T, shown in Figure 5.)
b) Dissipation Factor	The ratio of parallel reactance to the parallel resistance. (Determined at 60 Hertz and performed according to ASTM-D 150 on a General Radio Capacitance Measuring Assembly, Type 1610A, shown in Figure 6.)
c) Dielectric Constant	Comparison of the capacitance of a material to that of air, air being assigned a value of 1. (Determined at 60 Hertz and performed according to ASTM-D 150 on a General Radio Capacitance Measuring Assembly, Type 1610A, shown in Figure 6.)
d) Surface Resistivity	The resistance to flow of electrical current over the surface of a material. (Expressed in ohms and performed according to ASTM-D 527 on a Freed Megohmmeter Model 1620C and a General Radio Dielectric Sample Holder, shown in Figure 7).

TABLE I (Cont)

Test	Definition (as used in this program)
e) Volume Resistivity	The resistance in ohms-centimeter of a substance. (Expressed in ohm-centimeters and performed according to ASTM-D 527 on a Freed Megohmmeter Model 1620C and a General Radio Dielectric Sample Holder, shown in Figure 7.)
11) Outgassing	The percent weight change of a material due to the effect of pressures on the order of 10^{-6} mm Hg.
12) Color Compatibility	The effect of coatings on the appearance of colors. Colors were visually examined through a film of the material.
13) Environmental Tests	
a) Vibration (pre and post test)	The effect of high frequency vibration on electronic components soldered to printed circuit boards.
b) High Temperature	The electrical and mechanical effect on a comb resistance pattern etched on a printed circuit board, and on a board with inoperative electronic components (Figure 8), subjected to 250°F for 100 hours (Figure 9).
c) Low Temperature	The electrical and mechanical effect on a comb resistance pattern etched on a printed circuit board, and on a board with inoperative electronic components, subjected to -185°F for 48 hours.
d) Temperature Shock	The electrical and mechanical effect on a comb resistance pattern etched on a printed circuit board, and on a board with inoperative electronic components, subjected to cycling between -40°F and +300°F. Test performed similar to methods given in MIL-E-5272.

TABLE I (Cont)

Test	Definition (as used in this program)
e) Humidity	The electrical and mechanical effect on a comb resistance pattern etched on a printed circuit board, and on a board with inoperative electronic components, subject to high humidity for 10 days. Test performed according to MIL-STD-202, Method 106B.
f) Fungus	The extent of life-support engendered to fungus by the coatings during a 28 day exposure. Twenty-six 2 inch squares of sheet epoxy glass coated with the candidate materials served as test specimens. Tests performed in accordance with MIL-E-5272.

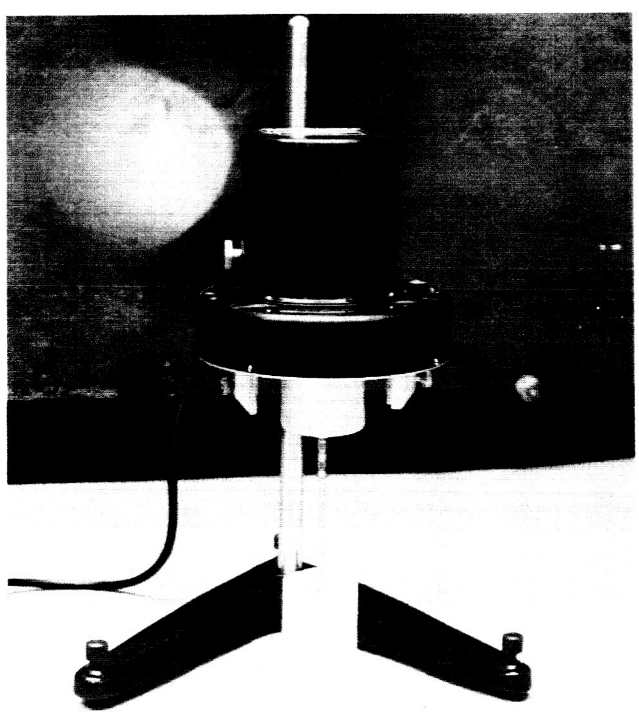


Figure 1. Brookfield Viscometer

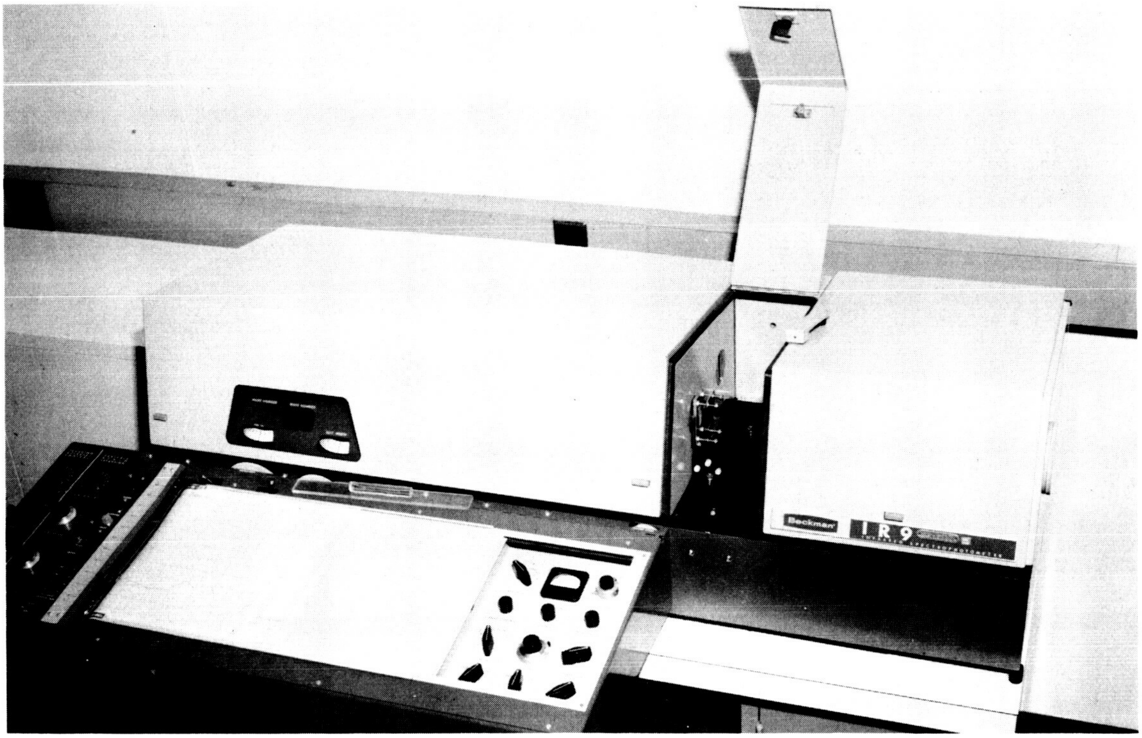


Figure 2. Beckman IR-9 Spectrophotometer Used in IR Analysis

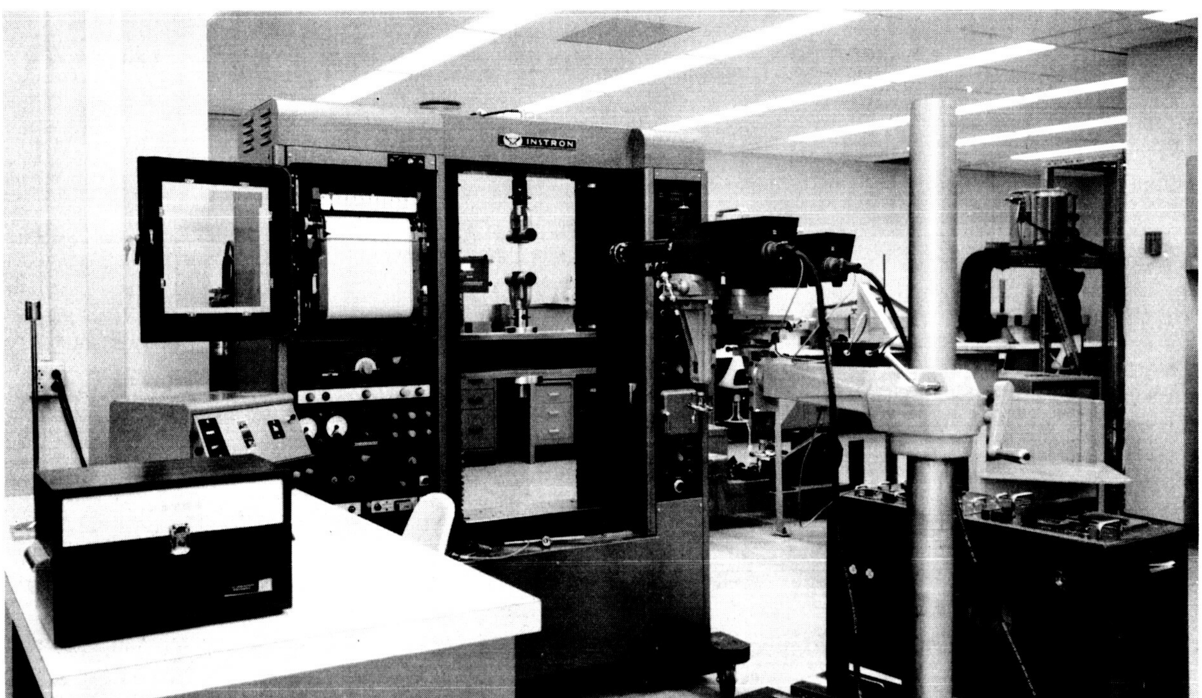


Figure 3. Instron Testing Machine Used to Determine Adhesion Strength

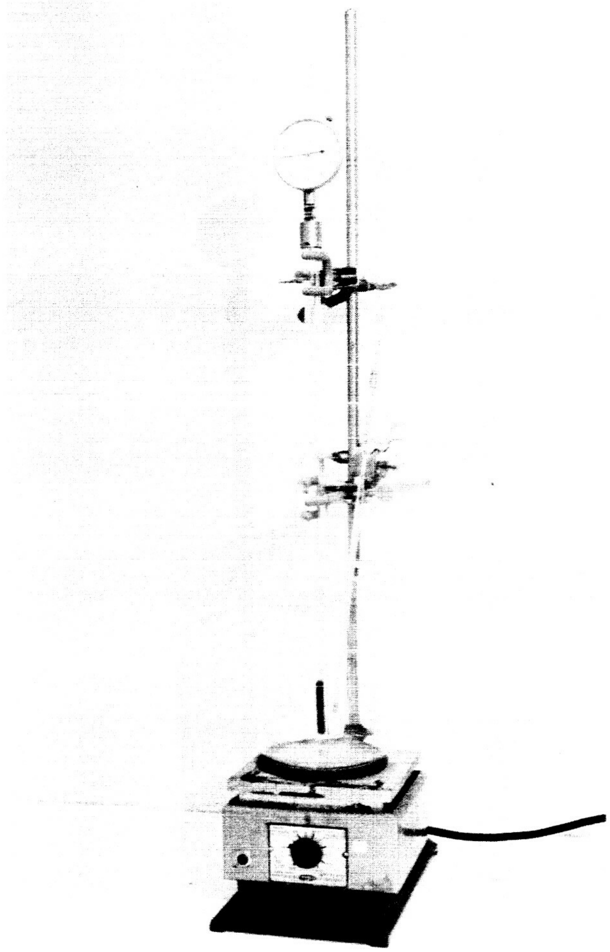
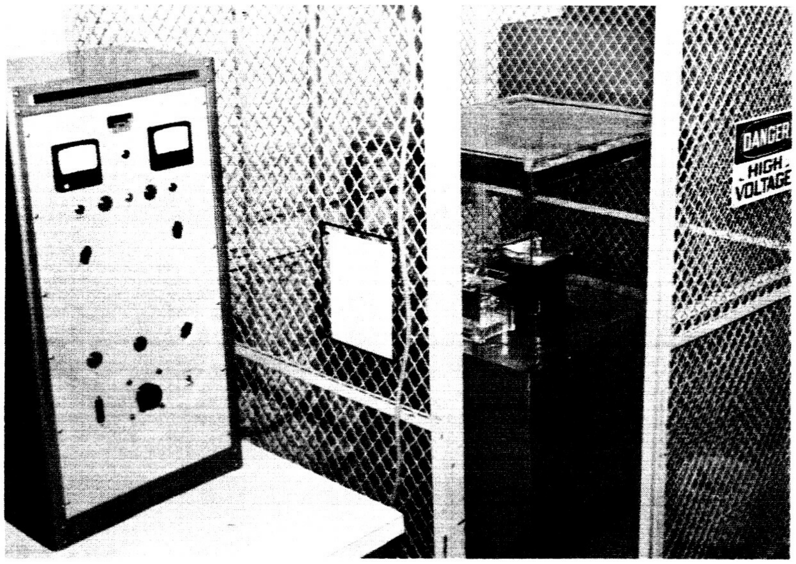


Figure 4. Quartz Tube Dilatometer
Used to Determine Coefficient
of Linear Thermal Expansion

Figure 5. Davenport
High Potential
Tester



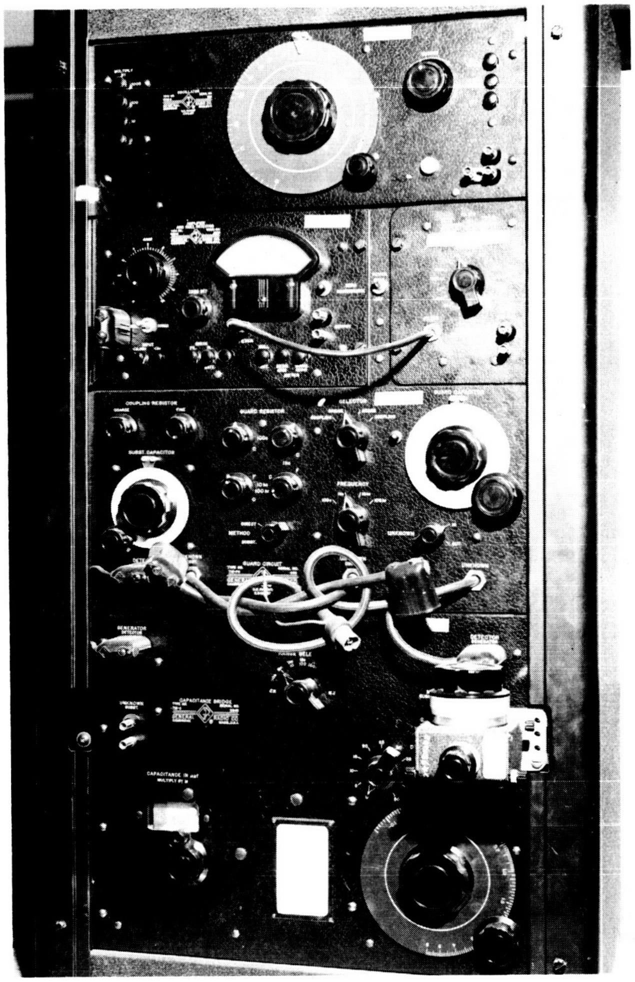


Figure 6. Capacitance Measuring Assembly for Determining Dielectric Constant and Power Factor

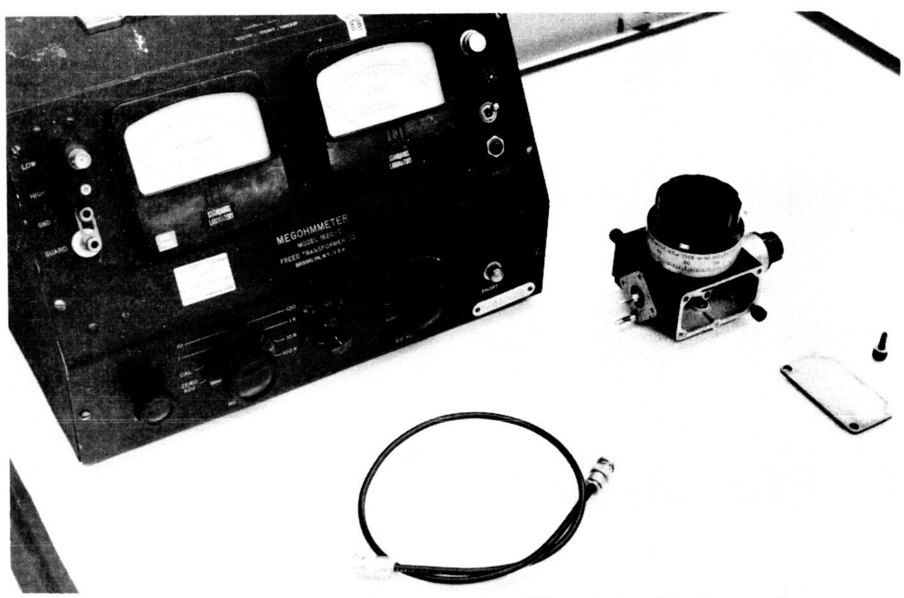


Figure 7. Megohmmeter Used to Determine Volume and Surface Resistivity

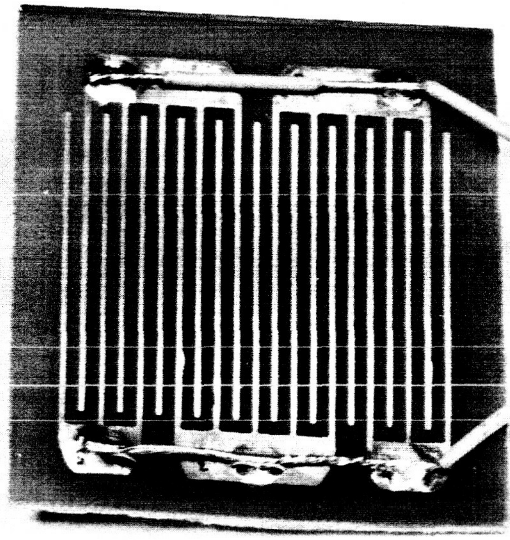


Figure 8. Comb Resistance Circuit Board Used in Environmental Tests

Figure 9. Inactive Component Circuit Board Used in Environmental Tests

A. MATERIALS SCREENED

The intial screening tests used to select the compounds were performed on 15 commercially available, and ten Martin prepared compounds. Of these 25 compounds, ten were chosen for the final, extensive evaluation. It was believed that this number of materials would include at least several coatings with satisfactory characteristics. Complete evaluation of a larger number of materials would have been beyond the scope of this program. Table II identifies the compounds tested, and lists those tests to which each material was subjected.

TABLE III

Compounds Screened and Tests Performed

Coating Designation	Type	Test Performed																
		Viscosity	Drying Time	Curing Cycle	Pot Life	Infrared Absorption	Transparency	Emissivity	Flexibility	Adhesion	Water Absorption	Thermal Expansion	Solderability	Chemical Resistance	Electrical Properties	Outgassing	Color Compatibility	Environmental Tests
1) Products Research PR 1538[1]	Polyurethane	T[3]	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
2) Uralane 5712[1]	Polyurethane	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
3) Humiseal 1A27[1]	Polyurethane	T	T	T	T	T	T	T	T	T	T	NT[8]	T	T	T	T	T	T
4) Humiseal 1A20	Polyurethane	T	T	T	NT[4]	T	T	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
5) Minnesota Mining and Manufacturing 3M221	Polyurethane	T	T	T	NT	T	T	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
6) Hysol PC 22[1]	Polyurethane	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
7) Hysol PC 15	Polyurethane	T	T	T	NT	T	T	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
8) Products Research 1566	Polyurethane	T	T	T	NT	T	T	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
9) Magnolia Plastics Magnobond 39[1]	Epoxy-Polysulfide	T	T	T	T	T	T	T	T	T	T	NT[8]	T	T	T	T	T	T
10) Shell Chemical Epon 871 + Epon 828 + Union Carbide L-520 Silicone + M-Phenylenediamine + Catalyst[2]	Epoxy-Silicone	T	T	T	T	T	US[5]	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
11) Shell Chemical Epon 871 + Epon 828 + M-Phenylenediamine + Catalyst[2]	Epoxy	NT	T	T	NT	T	US	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
12) Shell Chemical Epon 828 + Polyazelaic Polyanhydride + Benzyldimethylamine[2]	Epoxy	NT	T	T	NT	T	T	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
13) Union Carbide ERRA 0300 + M-Phenylenediamine + Catalyst[2]	Epoxy	NT	T	T	NT	T	T[6]	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
14) Union Carbide ERLA 0400 + M-Phenylenediamine + Catalyst[2]	Epoxy	NT	T	T	NT	T	T[6]	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
15) Hysol PC 16[1]	Epoxy	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
16) Minnesota Mining and Manufacturing 3M280[1]	Epoxy	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
17) Pyromellitic Dianhydride + M-Phenylenediamine in Dimethyl Acetamide[2]	Polyimide	NT	T	T	NT	T	US	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
18) Amoco Polymer 10[2]	Polyimide	NT	T	T	NT	T	T	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
19) Dupont Polyimide Binder Solution[2]	Polyimide	NT	T	T	NT	T	US	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
20) Martin Emissivity Coating[1, 2]	Acrylic	T	T	T	T	T	T	T	T	T	T	NT[8]	T	T	T	T	T	T
21) Humiseal 1B15	Acrylic	T	T	T	NT	T	T	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
22) Humiseal 1B12	Acrylic	T	T	T	NT	T	T	T	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
23) General Electric Lexan in Methylene Chloride[2]	Polycarbonate	T	T	T	NT	T	T[7]	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
24) Dow Corning Q92-009[1]	Silicone	T	T	T	T	T	T	T	T	T	T	NT[8]	T	T	T	T	T	T
25) General Electric SS4090[1]	Silicone	T	T	T	T	T	T	T	T	T	T	NT[8]	T	T	T	T	T	T

1 Finalist compound, completely evaluated.
2 Martin preparation.
3 T - Tested
4 NT - Not Tested
5 US - Tested, unsatisfactory
6 Coating cracked
7 Coating peeled, cloudy
8 Not tested due to softness of compound.

B. LIQUID COATING PROPERTIES

1. Viscosity

The viscosity of the compounds affects the handling and coating characteristics of the material. The lower viscosity compounds are sprayed more easily, but have a tendency to coat more thinly when the work piece is suspended on end and the material allowed to drain. Thicker, one coat films can be obtained by laying the specimen flat to prevent this run-off of resin.

Viscosities were determined on the liquid coatings immediately after mixing the components. A Brookfield Model RVF Viscometer with calibrated spindles was used for these tests and the values were determined at room temperature.

Viscosity was not determined for all compounds because some materials were eliminated from consideration prior to this stage of the testing for such reasons as opaqueness, cracking and low emissivity. Table III presents the viscosity values obtained.

All compounds were considered satisfactory with respect to this property.

TABLE III

Viscosity of Coatings

Coating Designation	Type	Viscosity[2] (Centipoise at 75°F)
Uralane 5712[3]	Polyurethane	9,200
Dow Corning Q92-009[3]	Silicone	9,000
Products Research PR 1538[3]	Polyurethane	8,000
Hysol PC 22[3]	Polyurethane	8,000
Hysol PC 16[3]	Epoxy	7,200
Minnesota Mining and Manufacturing 3M280[3]	Epoxy	3,800
General Electric SS4090[3]	Silicone	2,400
Magnolia Plastics Magnobond 39[3]	Epoxy-Polysulfide	280
Martin Emissivity Coating[1 and 3]	Acrylic	150
Humiseal 1A27[3]	Polyurethane	80
General Electric Lexan in Methylene Chloride[1]	Polycarbonate	1,000

TABLE III (Cont)

Coating Designation	Type	Viscosity[2] (Centipoise at 75°F)
Shell Chemical Epon 871 + Epon 828 + Union Carbide L-520 Silicone + M-Phenylenediamine + Catalyst[1]	Epoxy-Silicone	1,000
Minnesota Mining and Manufacturing 3M221	Polyurethane	900
Humiseal 1B15	Acrylic	470
Products Research PR 1566	Polyurethane	130
Humiseal 1A20	Polyurethane	80
Humiseal 1B12	Acrylic	40
Hysol PC 15	Polyurethane	25
Amoco Polymer 10[1]	Polyimide	(4)
Shell Chemical Epon 871 + Epon 828 + M-Phenylenediamine + Catalyst[1]	Epoxy	(4)
Shell Chemical Epon 828 + Polyazelaic Polyanhydride + Benzyldimethyl-amine[1]	Epoxy	(4)
Pyromellitic Dianhydride + M-Phenylenediamine in Dimethyl-acetamide[1]	Polyimide	(4)
Dupont Polyimide Binder Solution[1]	Polyimide	(4)
Union Carbide ERRA 0300 + M-Phenylenediamine + Catalyst[1]	Epoxy	(4)
Union Carbide ERLA 0400 + M-Phenylenediamine + Catalyst[1]	Epoxy	(4)

(1) Martin preparation
(2) The viscosity of the first ten listed materials was performed in the Martin Materials Laboratory; the remainder of the values are vendor data.
(3) Coating subjected to all tests.
(4) Eliminated from consideration before determination of viscosity.

2. Drying Time

The drying time was determined by applying thin coatings of the materials on small squares of aluminum, and determining the minimum time and temperature required to render the films tack-free. Short drying periods reduced handling time and therefore are desirable. Some of the compounds required elevated temperature to promote drying. However, this is not an untenable condition. All the compounds were satisfactory with respect to drying time. This is indicated in Table IV.

TABLE IV

Drying Time

Coating Designation	Type	Drying Time
General Electric SS4090(2)	Silicone	15 min at 75°F
Martin Emissivity Coating(1 and 2)	Acrylic	30 min at 75°F
Humiseal 1A27(2)	Polyurethane	30 min at 75°F
Dow Corning Q92-009(2)	Silicone	30 min at 75°F
Magnolia Plastics Mango-bond 39(2)	Epoxy-Polysulfide	15 min at 170°F
Hysol PC 16(2)	Epoxy	15 min at 170°F
Minnesota Mining and Manufacturing 3M280(2)	Epoxy	30 min at 170°F
Hysol PC 22(2)	Polyurethane	2 hours at 175°F
Uralane 5712(2)	Polyurethane	2 hours at 175°F
Products Research PR 1538(2)	Polyurethane	60 min at 180°F
Humiseal 1B12	Acrylic	10 min at 75°F
Humiseal 1B15	Acrylic	10 min at 75°F
Hysol PC 15	Polyurethane	10 min at 75°F
General Electric Lexan in Methylene Chloride(1)	Polycarbonate	10 min at 75°F
Humiseal 1A20	Polyurethane	25 min at 75°F
Minnesota Mining and Manufacturing 3M221	Polyurethane	3 hours at 75°F
Products Research 1566	Polyurethane	2 hours at 120°F
Pyromelletic Dianhydride + M-Phenylenediamine in Dimethylacetamide(1)	Polyimide	15 min at 175°F
Union Carbide ERRA 0300 + M-Phenylenediamine + Catalyst(1)	Epoxy	30 min at 185°F
Union Carbide ERLA 0400 + M-Phenylenediamine + Catalyst(1)	Epoxy	60 min at 185°F
Shell Chemical Epon 871		

TABLE IV (Cont)

Coating Designation	Type	Drying Time
+ Epon 828 + Union Carbide L-520 Silicone + M-Phenylenediamine + Catalyst(1)	Silicone	15 min at 200°F
Dupont Polyimide Binder Solution(1)	Polyimide	20 min at 200°F
Shell Chemical Epon 87p + Epon 828 + M-Phenylenediamine + Catalyst(1)	Epoxy	30 min at 200°F
Amoco Polymer 10 in Dimethylacetamide(1)	Polyimide	10 min at 250°F
Shell Chemical Epon 828 + Polyazelaic Poly-anhydride Benzyldimethyl-amine(1)	Epoxy	20 min at 250°F

(1) Martin preparation
(2) Coatings, subjected to all tests

3. Curing Cycle

Curing cycles were determined by applying thin coatings of the compounds on small squares of aluminum and determining the minimum time required to completely cure the coating. Complete cure was indicated by visual appearance, feel, and vendor data.

As in the case of drying time, short time, low temperature cure cycles are desirable to reduce the processing time. However, if a compound had such properties as good emissivity and good adhesive properties, a longer, higher temperature curing cycle was not used as a factor for elimination of a coating from this study. In some usages, a high cure temperature may not be desirable and in these cases, greater consideration should be given to the temperature rather than to the time of cure. All the candidate compounds are satisfactory with respect to curing cycle. The results of the tests are given in Table V.

TABLE V

Curing Cycle

Coating Designation	Type	Cure Cycle
Martin Emissivity Coating(1 and 2)	Acrylic	45 min at 130°F
Hysol PC 16(2)	Epoxy	2 hours at 170°F
Magnolia Plastics Magnobond 39(2)	Epoxy-Polysulfide	2 hours at 170°F
Humiseal 1A27(2)	Polyurethane	50 min at 175°F
Dow Corning Q92-009(2)	Silicone	60 min at 175°F
Hysol PC 22(2)	Polyurethane	16 hours at 175°F
Uralane 5712(2)	Polyurethane	16 hours at 175°F
Products Research PR 1538(2)	Polyurethane	4 hours at 180°F
Minnesota Mining and Manufacturing 3M280(2)	Epoxy	2 hours at 248°F
General Electric SS4090(2)	Silicone	20 min at 265°F
General Electric Lexan in Methylene Chloride(1)	Polycarbonate	30 min at 75°F
Products Research PR 1566	Polyurethane	16 hours at 120°F
Hysol PC 15	Polyurethane	10 min at 125°F
Humiseal 1B12	Acrylic	30 min at 170°F
Humiseal 1B15	Acrylic	30 min at 175°F
Humiseal 1A20	Polyurethane	30 min at 175°F
Pyromellitic Dianhydride + M-Phenylenediamine in Dimethylacetamide(1)	Polyimide	60 min at 175°F
Union Carbide ERRA 0300 + M-Phenylenediamine + Catalyst(1)	Epoxy	2 hours at 185°F
Union Carbide ERLA 0400 + M-Phenylenediamine + Catalyst(1)	Epoxy	6 hours at 185°F
Shell Chemical Epon 871 + Epon 828 + Union Carbide L-520 Silicone + M-Phenylenediamine + Catalyst	Epoxy-Silicone	2 hours at 200°F
Shell Chemical Epon 871 + Epon 828 + M-Phenylenediamine + Catalyst(1)	Epoxy	2 hours at 200°F

TABLE V (Cont)

Coating Designation	Type	Cure Cycle
Amoco Polymer 10 in Dimethylacetamide(1)	Polyimide	30 min at 250°F
Shell Chemical Epon 828 + Polyazelaic Polyanhydride + Benzyldimethylamine(1)	Epoxy	90 min at 257°F
Minnesota Mining and Manufacturing 3M221	Polyurethane	2 hours at 265°F
Dupont Polyimide Binder Solution(1)	Polyimide	2 hours at 350°F

(1) Martin preparation
(2) Coatings subjected to all tests.

4. Pot Life

Pot life is the work-life of a compound, at room temperature, after mixing the components and is defined as the length of time a coating is capable of being satisfactorily applied to an assembly.

A long pot life is a desirable characteristic allowing long handling periods of the uncured material. Single component systems, such as Dow Corning Q92-009, Martin Emissivity Coating, and Humiseal 1A27 are easy to work with, having virtually unlimited pot life, and requiring no weighing and mixing of constituents. Pot life was determined only on the ten coatings chosen for final extensive evaluation, as shown in Table VI.

All compounds tested are considered to have satisfactory pot life.

TABLE VI

Pot Life of Coatings

Coating Designation	Type	System
Dow Corning Q92-009	Silicone	One component system(2)
Martin Emissivity Coating(1)	Acrylic	One component system(2)
Humiseal 1A27	Polyurethane	One component system(2)
General Electric SS4090	Silicone	>1 hour at 75°F

TABLE VI (Cont)

Coating Designation	Type	System
Hysol PC 16	Epoxy	>1 hour at 75°F
Hysol PC 22	Polyurethane	>1 hour at 75°F
Magnolia Plastics Magnobond 39	Epoxy-Polysulfide	>1 hour at 75°F
Uralane 5712	Polyurethane	>1 hour at 75°F
Minnesota Mining and Manufacturing 3M820	Epoxy	>1 hour at 75°F
Products Research PR 1538	Polyurethane	1 hour at 75°F

(1) Martin preparation

(2) Long period pot life determined by length of time material is exposed to air.

5. Infrared Absorption

Infrared absorption was determined on a Beckman IR 9 Spectrophotometer. A film of the liquid coating was applied to a potassium bromide cell and a spectrum was run. Good emissivity was indicated by high absorption through the spectral range.

The prime prerequisite for the desired coating is that it has a high emissivity value. There is a relationship between emission and absorption of radiation that was used in this material study. This relationship shows that a high emissivity material also has low reflectance and high IR absorption. This is stated in Kirchoff's law as: Emissivity = Absorptivity x Constant. IR analysis was therefore used in the screening study to indicate those coating materials which were likely to have a high emissivity. This relationship was used only as a preliminary method of coating evaluation. The final analysis resulted from actual determinations of emissivity values. An examination of the IR versus the emissivity data does not show a readily apparent relationship. Table VII lists the frequencies at which the ten compounds selected for final evaluation have strong and medium strong absorption bonds. The characteristic general areas of absorption for generic type compounds evaluated in the overall study are also listed.

TABLE VII

Infrared Absorption Data

Coating Designation	Type	Major Absorption Bands (microns) Strong	Medium
Products Research PR 1538	Polyurethane	4.2 to 4.4, 5.8, 6.5, 6.8, 7.3, 7.7, 8.2, 8.9	10.5, 11.5, 12.1
General Electric SS 4090	Silicone	6.6, 7.8, 9.0, to 10.0, 12.2, 13.8, 14.3	6.2, 6.8
Hysol PC 22	Polyurethane	4.2-4.4, 5.7, 6.4, 8.1, 9.0	6.2, 6.8, 7.2, 10.6
Dow Corning Q92-009	Silicone	7.8, 9.0-10.0, 12.4	4.2, 6.8, 10.9
Uralane 5712	Polyurethane	4.3, 4.7, 6.5, 8.0, 9.0	6.2, 7.2, 10.0
Hysol PC 16	Epoxy	6.6, 8.0, 8.4, 9.6, 12.0	5.8, 6.2, 6.8, 8.8, 11.0
Martin Emissivity Coating(1)	Acrylic	5.7, 7.8 to 8.0	7.2, 9.5
Minnesota Mining and Manufacturing 3M280	Epoxy	6.6, 8.0, 9.6, 12.0	6.2, 6.8, 7.7
Humiseal 1A27	Polyurethane	5.7, 6.4, 8.2	4.2, 6.2, 6.8, 9.3, 13.0
Magnolia Plastics Magnobond 39	Epoxy-Polysulfide	7.9, 9.5	5.7, 6.2, 6.6, 12.0
Generic Types			
Acrylics		8-9	7.2
Polyurethane		5.8, 6.5, 8.0, 8.5, 9.0	10.0
Silicones		9-10	6.8

TABLE VII (Cont)

Coating Designation	Type	Major Absorption Bands (microns)	
		Strong	Medium
Epoxies		6.6, 8.0, 9.6	6.2, 6.8, 5.9, 6.4, 7.2, 8.0, 9.0
Polycarbonates		5.7, 6.5, 8-9 9.8, 12.0, 13-14	

(1) Martin preparation.

C. CURED COATING PROPERTIES

1. Transparency

Transparency was determined by visually examining thin films of the cured coatings. These films were about 5 to 10 mils thick.

A necessary characteristic of the cured conformal coating is that it be transparent, at least to the point of not obscuring part identification when applied to electronic components. Some of the coatings were observed to be opaque, or of such a dark color that they were eliminated from further consideration as possible contenders. In addition some of the coatings cracked on curing, and thus were eliminated. Other coatings were found to be amber or slightly cloudy. However, these latter mentioned compounds, although not absolutely clear, were still transparent enough in the film thickness range required to be acceptable. All of the ten coatings shown in Table VIII were considered satisfactory with respect to transparency.

2. Coating Emissivity

The final screening test to determine the emissivity of the coatings evaluation was made by comparative techniques rather than by absolute measurement of emissivity since absolute measurement was neither necessary nor advisable in view of the time required to obtain these absolute measurements.

TABLE VIII

Transparency of Cured Coating

Coating Designation	Type	Appearance
General Electric SS4090(4)	Silicone	Clear
Hysol PC 16(4)	Epoxy	Clear
Hysol PC 22(4)	Polyurethane	Clear
Martin Emissivity Coating(1 and 4)	Acrylic	Clear
Products Research PR 1538(4)	Polyurethane	Clear
Uralane 5712(4)	Polyurethane	Clear
Dow Corning Q92-009(4)	Silicone	Slightly cloudy, transparent
Magnolia Plastics Magnobond 39(4)	Epoxy-Polysulfide	Light amber, transparent
Minnesota Mining and Manufacturing 3M280(4)	Epoxy	Light amber, transparent
Humiseal 1A27(4)	Polyurethane	Amber, transparent
Humiseal 1A20	Polyurethane	Clear
Humiseal 1B15	Acrylic	Clear
Humiseal 1B12	Acrylic	Clear
Amoco Polymer 10	Polyimide	Light amber, transparent
Hysol PC 15	Polyurethane	Pale pink, transparent
Products Research PR 1566	Polyurethane	Amber, transparent
Minnesota Mining and Manufacturing 3M221	Polyurethane	Amber, transparent
Polyazelaic Polyanhydride + Epon 828 + Benzyldimethylamine	Epoxy	Amber, transparent
Union Carbide ERLA 0400 + M-Phenylenediamine + Catalyst	Epoxy	Amber, cracked(3)
Union Carbide ERRA 0300 + M-Phenylenediamine + Catalyst	Epoxy	Amber, cracked(3)
Shell Chemical Epon 871 + Epon 828 + M-Phenylenediamine + Catalyst	Epoxy	Dark amber(2)
Shell Chemical Epon 871 + Epon 828 + Union Carbide L-520 Silicone		

TABLE VIII (Cont)

Coating Designation	Type	Appearance
+ M-Phenylenediamine + Catalyst	Epoxy-Silicone	Dark amber(2)
General Electric Lexan in Methylene Chloride	Polycarbonate	Cloudy, peeled from substrate on curing(3)
Polymellitic Dianhydride + M-Phenylenediamine in Dimethylacetamide	Polyimide	Opaque(3)
Dupont Polyimide Binder Solution	Polyimide	Opaque(3)

(1) Martin preparation.
(2) Coating darkened with age. Eliminated from further consideration.
(3) Eliminated from consideration.
(4) Coatings subjected to all tests.

Squares of aluminum, 1.0 x 1.0 x 0.040 inch, were each coated with the material to be evaluated. The squares were then individually placed on a steel platen using Dow Corning DC-4 as a thermal coupling medium. The temperature of the platen was controllable to less than 0.1°C between 35°C and 85°C. It was raised to 55°C and the infrared output of all coatings compared. The output levels of the compounds is given in Table IX.

TABLE IX

Relative Emissivity Values

Coating Designation	Type	Relative Emissivity
Martin Emissivity Coating(1 and 4)	Acrylic	25.2
Products Research PR 1538(2 and 4)	Polyurethane	25.2
Humiseal 1A27(4)	Polyurethane	25.1
Magnolia Plastics Magnobond 39(2 and 4)	Epoxy-Polysulfide	25.0
Uralane 5712(4)	Polyurethane	25.0
Hysol PC 22(4)	Polyurethane	24.9
Humiseal 1A20	Polyurethane	24.6

TABLE IX (Cont)

Coating Designation	Type	Relative Emissivity
Shell Chemical Epon 871 + Epon 828 + Union Carbide L-520 Silicone + M-Phenylenediamine + Catalyst(1 and 3)	Epoxy-Silicone	24.6
Hysol PC 16(2 and 4)	Epoxy	24.3
Dow Corning Q92-009(4)	Silicone	24.1
Shell Chemical Epon 871 + Epon 828 + M-Phenylenediamine + Catalyst(1)	Epoxy	24.1
Minnesota Mining and Manufacturing 3M280(4)	Epoxy	24.1
Minnesota Mining and Manufacturing 3M221	Polyurethane	24.0
General Electric SS4090(4)	Silicone	23.5
Shell Chemical Epon 828 + Polyazelaic Polyanhydride + Benzyldimethylamine(1)	Epoxy	23.3
Hysol PC 15	Polyurethane	23.2
Products Research PR 1566	Polyurethane	22.5
Amoco Polymer 10(1)	Polyimide	21.9
Humiseal 1B15	Acrylic	20.1
General Electric Lexan in Methylene Chloride(1)	Polycarbonate	18.3
Humiseal 1B12	Acrylic	16.7

(1) Martin preparation
(2) Material previously qualified for use as a conformal coating at Martin.
(3) Subsequently eliminated due to darkening with age.
(4) Coatings subjected to all tests.

D. SELECTED COATINGS

Final selection of ten coatings to be subjected to further evaluation tests was predominantly based on compounds with the highest emissivity. The original choice of ten coatings included the following which were subsequently replaced for the stated reasons: 1) Minnesota Mining and Manufacturing 3M221 - replaced by Martin Emissivity Coating which had superior emissivity, drying time, and cure properties; 2) Humiseal 1A20 – replaced by Uralane 5712 due to a loss of a shipment of the former, in transit between the vendor and Martin; 3) Shell Chemical Epon 871 + Epon 828 +

M-Phenylenediamine + Catalyst - replaced by Hysol PC 22 due to the similarity of the former coating with another of the original 10 candidate materials (Shell Chemical Epon 871 + Epon 828 + Union Carbide L-520 Silicone + M-Phenylenediamine + Catalyst) and due to excessively long mixing time required by the multicomponent constituents. This compound also turned an excessively dark color, and was eliminated from consideration; 4) Shell Chemical Epon 871 + Epon 828 + Union Carbide L-520 Silicone + M-Phenylenediamine + Catalyst – Replaced by General Electric SS4090 due to the darkening with age of the former material. SS4090 was chosen due to its relatively high emissivity, and also to increase the number of silicone type materials among the ten finalists.

The final choice of ten compounds to be subjected to further evaluation are as follows:

Martin Emissivity Coating
Products Research PR 1538
Humiseal 1A27
Magnolia Plastics Magnobond 39
Uralane 5712
Hysol PC 22
Hysol PC 16
Dow Corning Q92-009
General Electric SS4090
Minnesota Mining and Manufacturing 3M280

Within the limitations of the contract, these ten coatings rate the highest of those tested. All of the initially selected coatings were not completely tested due to time and cost limitations. Martin-Orlando realizes that some of the coatings not tested could have superior characteristics in certain extended test areas.

III. EXTENDED TESTS

The 10 coatings selected as the result of the screening tests were subjected to further tests to rank them in order of their preference for each physical property. Thus, in the remainder of the tables the coatings are listed in order of preference.

A. MAXIMUM USE TEMPERATURE

Vendor contact, literature study, and laboratory experience revealed that the maximum continuous use temperature of the majority of the coatings under study was approximately 250°F. Whenever applicable, this limitation was observed during all testing, with the exception of the elevated temperature electrical properties tests where equipment limitations dictated a maximum temperature of 200°F.

B. FLEXIBILITY

The flexibility of a compound affords a measure of the effect of coating expansion on embedded electrical components. This property was evaluated by examining 4 by 4 by 1/8 inch flat sheets of the cured coatings, and rating the compounds "Very Good," "Good," or "Fair." The polyurethanes and silicones all rated as "Very Good," except for Humiseal 1A27 which did not have the elasticity of the others, and was therefore rated as "Good." The epoxies, Hysol PC 16 and Minnesota Mining and Manufacturing 3M280 were classified as "Fair" due to their somewhat rigid structure. Magnobond 39, an epoxy, and Martin Emissivity Coating, an acrylic, were somewhat soft at room temperature, but were not as elastic as the polyurethanes. These latter two compounds were rated as "Good" with respect to flexibility. Table X lists the compounds and their ratings.

C. ADHESION

The adhesion test was performed in accordance with ASTM-D 903. This consists of bonding a strip of untreated canvas to the material which will be used as the substrate in the final application, in this case an epoxy-glass printed circuit board. The coating compound under test is used as the bonding agent. The canvas is then cut into 1 inch wide strips and peeled in a 180 degree direction from the board, at a speed of 10 inches per minute.

TABLE X

Flexibility of Cured Coatings

Coating Designation	Type	Rating
Dow Corning Q 92-009	Silicone	Very good, rubber like
General Electric SS4090	Silicone	Very good, rubber like
Hysol PC22	Polyurethane	Very good, rubber like
Products Research PR1538	Polyurethane	Very good, rubber like
Uralane 5712	Polyurethane	Very good, rubber like
Magnolia Plastics Magnobond 39	Epoxy-polysulfide	Good
Martin Emissivity Coating(1)	Acrylic	Good
Humiseal 1A27	Polyurethane	Good
Hysol PC16	Epoxy	Fair
Minnesota Mining and Manufacturing 3M280	Epoxy	Fair

1 Martin preparation.

An Instron testing machine was used for this operation (Figure 3). The majority of the values listed are the minimum value which could be expected in actual usage, due to the fact that the failure occurred at some interface other than at the printed circuit board surfaces.

Epoxies Hysol PC 16 and Magnobond 39 and urethanes Hysol PC 22, Products Research PR 1538, and Uralane 5712 all displayed very good adhesive quality. In each case, the adhesive testing of these materials resulted in failure of the bond in some place other than at the surface of the printed circuit board. Silicones Dow Corning Q 92-009, General Electric SS4090 and the acrylic Martin Emissivity Coating failed at relatively low values, but here too, the failure did not occur at the working surface of the printed circuit board. Minnesota Mining and Manufacturing Company 3M280, and Humiseal 1A27 failed at the board surface, at 5 pounds per inch. Table XI gives the results of the adhesion tests.

D. WATER ABSORPTION

Table XII lists the coatings under study, with water absorption characteristics, in order of performance. The water absorption test was performed using a procedure similar to that in ASTM D570. The specimens were conditioned before testing in an oven for 8 hours at 125°F, weighed on an analytical balance, and immersed in water at room temperature for 24 hours. At the end of this period, the specimens were quickly wiped with

TABLE XI

Adhesion of Coatings

Compound	Type	Adhesion (lb/in.)[2] and Failure Mode
Hysol PC 16	Epoxy	>20 Canvas broke
Hysol PC 22	Polyurethane	>20 Cohesive Failure in resin
Magnolia Plastics Magnobond 39	Epoxy-polysulfide	>18 Adhesive Failure at canvas
Products Research PR 1538	Polyurethane	>15 Cohesive Failure in resin
Uralane 5712	Polyurethane	>15 Cohesive Failure in resin
Dow Corning Q 92-009	Silicone	>6 Adhesive Failure at canvas
General Electric SS4090	Silicone	>5 Cohesive Failure in resin
Martin Emissivity Coating[1]	Acrylic	>5 Cohesive Failure in resin
Minnesota Mining and Manufacturing 3M280	Epoxy	5 Adhesive Failure at board
Humiseal 1A27	Polyurethane	5 Adhesive Failure at board

(1) Martin preparation

(2) 180 degree peel test of 1 inch wide canvas cloth bonded to printed circuit board with test compound in accordance with ASTM-D 903.

an absorbent towel, then reweighed on the analytical balance. Weight change was calculated in terms of percent.

General Electric SS4090 silicone showed negligible absorption of water over the test period. Minnesota Mining and Manufacturing 3M280 (Epoxy) and Dow Corning Q 92-009 (Silicone) also had low water absorption values. All but one of the remaining compounds absorbed less than approximately 0.6 percent water. Hysol PC 22, a urethane, absorbed 1.4 percent, a relatively high amount.

TABLE XII

Water Absorption of Coatings

Compound	Type	Water (2) Absorption %Wt Change
General Electric SS 4090	Silicone	Negligible
Minnesota Mining and Mfg Company 3M280	Epoxy	+0.06
Dow Corning Q 92-009	Silicone	+0.15
Uralane 5712	Polyurethane	+0.25
Humiseal 1A27	Polyurethane	+0.36
Products Research PR1538	Polyurethane	+0.37
Magnolia Plastics Magnobond 39	Epoxy-polysulfide	+0.43
Hysol PC 16	Epoxy	+0.53
Martin Emissivity Coating (1)	Acrylic	+0.58
Hysol PC 22	Polyurethane	+1.40

(1) Martin preparation
(2) Percent weight change after 24-hour immersion in water at room temperature.

E. COEFFICIENT OF LINEAR THERMAL EXPANSION

The coefficient of linear thermal expansion (CLTE) was determined in a manner similar to that given in ASTM D696-44. A Tinius Olsen Quartz Tube Dilatometer graduated in units of 0.0001 inch was used (Figure 4). As stated in ASTM D696, this method is not applicable to plastics which will not support the weight of the quartz tube without distortion. Therefore, it was not possible to determine the coefficient of linear expansion of all the materials under study. However, due to the softness of such materials as General Electric SS4090 and Dow Corning Q 92-009, their expansion and contraction would not stress coated components to the extent that a firmer material of similar expansion would. The polyurethanes had somewhat greater expansions than did the epoxies. The temperature range between +32° and +80°F was investigated and considered to be in the area of greatest interest. Higher temperatures would have unduly softened the materials and led to erroneous results. No great difference in CLTE was noted in the test values. Table XIII shows the results of the tests.

TABLE XIII

Coefficient of Linear Thermal Expansion of Coatings

Compound	Type	Coefficient of Linear Thermal Expansion In./In./°F (32° - 80°F)
Hysol PC 16	Epoxy	4.76×10^{-5}
Minnesota Mining and Mfg 3M280	Epoxy	5.52×10^{-5}
Uralane 5712	Polyurethane	7.93×10^{-5}
Hysol PC22	Polyurethane	1.20×10^{-4}
Products Research PR 1538	Polyurethane	1.00×10^{-4}
Dow Corning Q92-009	Silicone	(2)
General Electric SS4090	Silicone	(2)
Magnolia Plastics Magnobond 39	Epoxy-polysulfide	(2)
Martin Emissivity Coating (1)	Acrylic	(2)
Humiseal 1A27	Polyurethane	(2)

(1) Martin Preparation
(2) Material could not be made into test configuration. Material too soft for testing.

F. SOLDERABILITY

Solderability characteristics were evaluated by determining the ease with which the coatings could be removed from a component solder joint, for subsequent removal and replacement of the component. Prior to re-soldering, the joint was cleaned with Kester AP20. All of the coatings were found to be readily resolderable, although some displayed a tendency to melt and degrade more than others. This condition requires a more careful cleaning operation of the joint before and after resoldering. All of the compounds tested were considered satisfactory with respect to solderability as shown in Table XIV.

G. CHEMICAL RESISTANCE

Table XV gives the effect of various solutions on the thickness, weight, and appearance of the coatings, after four days immersion at room temperature. The solutions used were as follows:

TABLE XIV

Solderability of Coatings

General Electric SS4090	Silicone	Coating easily removed. Very little degradation of coating. Resolders well.
Dow Corning Q 92-009	Silicone	Coating easily removed. Joint easily cleaned. Resolders well.
Hysol PC 16	Epoxy	Coating easily removed. Joint easily cleaned. Joint resolders well.
Minnesota Mining and Mfg 3M280	Epoxy	Coating easily removed. Joint easily cleaned. Resolders well.
Hysol PC 22	Polyurethane	Coating melts on heating with iron. Joint must be cleaned well. Joint resolders well.
Uralane 5712	Polyurethane	Coating melts on heating with iron. Must be cleaned well with solvent. Joint resolders well.
Products Research PR1538	Polyurethane	Coating melts on heating with iron. Must be cleaned well with solvent. Joint resolders well.
Martin Emissivity Coating (1)	Acrylic	Coating easily removed but joint must be cleaned well with solvent. Joint resolders well.
Magnolia Plastics Magnobond 39	Epoxy-polysulfide	Coating easily removed. Must be cleaned well with solvent. Joint resolders well.
Humiseal 1A27	Polyurethane	Coating melts on heating with iron. Must be cleaned well with solvent. Joint resolders well.

(1) Martin Preparation

(2) Coating removed with a hot soldering iron (50 watt). Joint cleaned with Kester AP20 solvent.

TABLE XV

Chemical Resistance of Coatings

	Type	Isopropyl Alcohol		Methylethyl Ketone		Trichloroethylene		Solder Flux Kester 1544		Flux Remover Kester AP20	
		Thickness Change %	Weight Change %	Thickness Change %	Weight Change %	Thickness Change %	Weight Change %	Thickness Change %	Weight Change %	Thickness Change %	Weight Change %
Magnolia Plastics Magnobond 39	Epoxy-Poly-sulfide	+1.1 Good appearance Strong	-1.2	+15.0 Increase in flexibility	+276	+16.2 Bleached Flexible and strong	+75.8	-6.8 Yellowed Flexible and strong	-1.0	-1.4 Good appearance Flexible and strong	+2.4
Dow Corning Q92-009	Silicone	-3.0 Good appearance Flexible and strong	-4.2	+16.4 Flexible and strong	+14.7	+42.9 Flexible and strong	+248	+40.5 Good appearance Flexible and strong	+42.1	+37.4 Curled. Flexible but weakened	+183
Hysol PC22	Poly-urethane	+22.6 Flexible and strong	+59.1	+66.7 Weakened	+243	+72.3 Flexible and strong	+315	+21.5 Yellowed. Weakened	+89.0	+37.3 Flexible and strong	+194
Uralane 5712	Poly-urethane	+9.0 Good appearance Flexible and strong	+13.4	+43.7 Flexible but weakened	+116	+38.7 Flexible and strong	+165	+21.5 Yellowed but strong	+45.0	+20.4 Flexible and strong	+94.2
Hysol PC16	Epoxy	+3.0 Good appearance Strong	+3.0	+6.6 Cracked. Softened.	+15.3	(2) Crumbled	(2)	+2.5 Strong	+3.0	+7.9 Crumbles when bent	+42.5
General Electric SS4090	Silicone	+32.0 Flexible and strong	+43.0	+60.1 Flexible but weakened	+197	+93.8 Grossly swollen. Crumbles	+817	+15.4 Good appearance Flexible and strong	-30.0	+86.9 Grossly swollen. Weak	+810
Minnesota Mining and Manufacturing Company 3M280	Epoxy	+2.5 Good appearance Strong	+5.1	+23.9 Specimen crumbled as it dried	(2)	+23.6 Specimen crumbled	(2)	+1.2 Good appearance Strong	+5.1	+22.0 Specimen crumbled easily	+120
Products Research PR1538	Poly-urethane	+22.0 Swollen, bleached, weakened	+55.6	+46.5 Flexible but weakened	+126	+53.7 Bleached. Weakened	+320	+27.3 Yellowed. Weakened	+112	+39.4 Weakened	+142
Martin Emissivity(1) Coating	Acrylic	(2) Softened within 1 hour	(2)	+35.9 Swollen within 1 hour	+144	(2) Dissolved within 1 hour	(2)	(2) Softened within 1 hour	(2)	+16.2 Curled, no strength	+33.5
Humiseal 1A27	Poly-urethane	(2) Softened within 1 hour	(2)	(2) Dissolved within 1 hour	(2)	(2) Dissolved within 1 hour	(2)	(2) Dissolved within 3 days	(2)	(2) Dissolved within 3 days	(2)

(1) Martin Preparation
(2) Specimen could not be handled due to crumbling, softening, or dissolution.

1. Isopropyl alcohol - a commonly used cleaner for plastics.
2. Methylethyl ketone - cleaner solvent used in conjunction with plastics
3. Trichloroethylene - cleaner solvent used in conjunction with plastics
4. Solder flux, Kester 1544 - flux used on solder joints in the printed circuit board area at Martin
5. Flux remover, Kester AP20 used at Martin to clean solder joints.

The coatings have been listed in descending order of general performance in the solutions. However, it may be more desirable to evaluate the coatings with respect to a single environment. If this were the case, the order of rating might change from that presented.

As would generally be expected, methylethyl ketone and trichloroethylene had a more severe effect on the coatings tested than did isopropyl alcohol.

H. ELECTRICAL PROPERTIES

Room temperature and elevated temperature of 200°F electrical property data is given in Table XVI. The coatings are arranged in the table according to their overall electrical property performance.

Thin coatings tend to give higher dielectric strength values than thicker coatings of the same material. Therefore, an attempt was made to use sheets of uniform thickness for this test. However, this was not always possible due to the presence of volatiles in some of the coatings.

Humiseal 1A27 softened excessively at 200°F as it was being conditioned for the determination of its electrical properties at elevated temperature. However, the manufacturer states that the material is serviceable at 220°F, and lists electrical properties at this temperature. This data could not be reproduced at Martin due to the softening of the material. The Martin emissivity coating also softened excessively at 200°F, making it impossible to determine electrical properties at this temperature. Therefore, in view of this elevated temperature performance, the polyurethane Humiseal 1A27 and the acrylic Martin Emissivity Coating are rated as having the least satisfactory overall electrical properties of those coatings tested.

TABLE XVI

Electrical Properties of Coatings

Coating	Type		Dielectric Constant (60 Hertz)	Dissipation Factor (60 Hertz)	Surface Resistivity (ohms)	Volume Resistivity (ohm-cm)	Dielectric Strength (volts/mil)	Specimen Thickness (inches)
Dow Corning Q92-009	Silicone	RT(2)	2.94	0.00063	1.30×10^{13}	3.08×10^{14}	674	0.015
		200°F	2.78	0.00048	3.05×10^{12}	2.02×10^{14}	958	0.050
General Electric SS4090	Silicone	RT	2.74	0.00049	1.52×10^{13}	1.40×10^{12}	500	0.045
		200°F	2.54	0.0015	3.05×10^{14}	6.35×10^{12}	395	0.045
3M280(3)	Epoxy	RT	3.34	0.0070	2.34×10^{13}	3.13×10^{13}	405	0.122
		200°F	5.22	0.0051	1.15×10^{13}	2.96×10^{12}	400	0.123
Hysol PC16	Epoxy	RT	4.20	0.016	1.67×10^{13}	1.48×10^{13}	428	0.120
		200°F	9.04	0.141	5.28×10^{11}	3.27×10^{10}	274	0.120
Products Research 1538	Poly-urethane	RT	6.58	0.019	1.27×10^{13}	1.31×10^{12}	309	0.122
		200°F	6.86	0.066	7.37×10^{11}	4.47×10^{10}	493	0.122
Uralane 5712	Poly-urethane	RT	5.15	0.024	2.08×10^{13}	6.51×10^{12}	352	0.122
		200°F	6.10	0.011	5.79×10^{11}	2.42×10^{11}	464	0.123
Hysol PC22	Poly-urethane	RT	6.98	0.029	5.33×10^{12}	2.66×10^{11}	428	0.124
		200°F	7.37	0.042	3.30×10^{11}	1.31×10^{10}	443	0.124
Magnolia Magnobond 39	Epoxy-Poly-sulfide	RT	6.80	0.018	2.80×10^{13}	5.05×10^{12}	1500	0.128 0.08 (Di Str)
		200°F	8.0	0.40	6.30×10^{11}	4.04×10^{9}	450	0.128
Humiseal 1A27	Poly-urethane	RT	2.90	0.0026	3.65×10^{12}	1.18×10^{14}	1005	0.022
		220°F(4)	3.7(4)	0.010(4)	6.0×10^{9}(3)	2.00×10^{13}(4)	2400(4)	Not given
Martin Emissivity Coating(1)	Acrylic	RT	2.13	0.065	1.52×10^{13}	1.62×10^{12}	400	0.050
		200°F	(5)	(5)	(5)	(5)	(5)	

(1) Martin Preparation
(2) Room Temperature (RT)
(3) Minnesota Mining and Manufacturing Company (3M)
(4) Vendor Data
(5) Material not serviceable at 200°F

I. OUTGASSING

For this determination, the ten candidate materials were conditioned at 130°F for eight hours in an oven and then placed in a dessicator for 48 hours. The materials were then removed singly from the dessicator and weighed to the nearest tenth of a milligram on a Mettler Analytical Balance. After weighing, the materials were placed in a vacuum chamber and the pressure reduced to approximately 5.0×10^{-6} mm of mercury. This reduced pressure was held for approximately five hours. At the conclusion of this hold period, the pressure was gradually allowed to return to ambient. The samples were then removed, placed into a dessicator, and then singly removed and subsequently reweighed on the Mettler Balance.

Two test specimens represented each coating. The epoxies lost little to no weight. The polyurethanes, for the most part, lost a small amount of weight. The solvent-containing systems, such as General Electric SS4090 and Martin Emissivity Coating suffered the greatest weight loss. One compound, Humiseal 1A27, displayed a slight weight gain of 0.1 percent. This weight gain could possibly be attributable to moisture pickup immediately subsequent to outgassing, during return to ambient pressure. Specimen size was about 1.5 to 2.5 grams in sheet form. Table XVII shows results of the tests.

TABLE XVII

Weight Change Caused By Outgassing of Coatings

Material Designation	Type	Weight Change -%
Hysol PC16	Epoxy	Nil
Minnesota Mining and Manufacturing 3M280	Epoxy	Nil
Hysol PC 22	Polyurethane	-0.09
Humiseal 1A27	Polyurethane	+0.10
Magnolia Plastics Magnobond 39	Epoxy-polysulfide	-0.14
Products Research PR1538	Polyurethane	-0.14
Dow Corning Q 92-009	Silicone	-0.51
Uralane 5712	Polyurethane	-0.79
Martin Emissivity Coating (1)	Acrylic	-0.94
General Electric SS4090	Silicone	-5.51

(1) Martin Preparation

J. COLOR COMPATIBILITY

A color compatibility test was also performed. This consisted of painting strips of various colors commonly used to identify electronic component values, on a sheet of glass and then coating glass microscope slides with the coatings under study. The colors then were viewed through the coatings. No masking or alteration of the colors was noted.

K. ENVIRONMENTAL TESTS

The follow environmental tests were performed: 1) Vibration, 2) High Temperature Resistance, 3) Low Temperature Resistance, 4) Temperature Shock, 5) Humidity Resistance, 6) Post Vibration and 7) Fungus. Each of these tests is described in Table XVIII.

TABLE XVIII

Summary of Environmental Test Conditions

Environmental Test	Test Time Duration	Test Condition	Tests Conducted	Applicable Test Specification	Comments
Humidity	10 days	Temperature limit of 149°F	Resistance checked at end of first, third and tenth test day.	MIL-STD-202 Method 106B	No application of power or vibration during test.
High Temperature	100 hours	250°F	Resistance checked every 24 hours, starting at 48 hours. Resistance checked before and after elevated temperature.	Similar to MIL-E-5272	No electrical load applied during temperature application.
Low Temperature	48 hours	-65°F	Resistance checked before and one hour prior to test termination.	Similar to MIL-E-5272	
Temperature Shock	3 cycles of 2 hours	-40°F to +185°F with 5 minute transfer time	Resistance checked before and after environment.	Similar to MIL-E-5272	
Fungus	28 days		Visual examination only.	MIL-E-5272	
Vibration	3 minutes in each of 3 axes	Random vibration envelope equivalent to 38.5g rms	Visual examination before and after environment.	MIL-STD-810 Method 514.1 Random Test Curve J	No application of power during test.

Samples of each type of coating tested were applied to each of three printed circuit boards which had interlocking comb resistance circuits, with separations of about 0.05 inch between positive and negative patterns. (Figure 8). Three other boards consisting of printed circuits with inactive electronic components attached, were also used for each type of coating

(Figure 9). In addition, two boards for each type of coating tested, were used to perform the fungus test only. These latter boards did not contain any circuits or components.

The order of performing the environmental tests along with the type of sample board used for each is as follows:

1	Vibration	Boards with electronic components only
2	High temperature	Comb pattern and component boards
3	Low temperature	Comb pattern and component boards
4	Temperature shock	Comb pattern and component boards
5	Humidity	Comb pattern and component boards
6	Post Vibration	Boards with electronic components only
7	Fungus	Boards with no components or comb pattern

1. Equipment Used in Environmental Testing Program

The following equipment was used in the environmental tests:

1 Hot Chamber - 5 x 4 x 2 1/2 Foot hot pack chamber
Capability - ambient to 650°F
Circular chart recording

2 Low Temperature - 4 x 4 x 4 Foot Webber low temperature chamber
Capability - ambient to -100°F
Strip chart recording
Model No. WE 64-120T

3 Humidity - 4 x 4 x 6 Foot International Radiant
Capability - 20 to 100 percent RH
Temp 60°F to 200°F
Circular chart recording and controlling

4 Fungus - 4 x 8 x 12 Foot International Radiant
Capability - 95 to 100 percent RH
60°F to 250°F
Circular chart recording

5 Vibration - MB-C-210 vibration exciter
Capability 6,000 pounds force and
Sine and Random motion
Automatic equalization - 80 channels
5 cps to 3 kc

6 Resistance - Freed Megohmmeter
500 volts for all measurements

2. Pretest Insulation Values

Insulation readings were taken with a Freed Megohmmeter and 500 volts dc potential applied to the comb resistor pattern boards prior to application of coatings. All values were satisfactory, measuring at least 1×10^{12} ohms. After application of the individual coatings, the resistance readings were repeated. The values are listed in Table XIX. The coating thickness on each individual board is also given in this table.

TABLE XIX

Resistance After Application of Coatings

Material Designation	Type	Test Board Number	Coating Thickness (Inches)	Resistance (Ohms)
Humiseal 1A27	Polyurethane	8	0.003	1.5×10^{12}
		9	0.003	1.5×10^{12}
		10	0.002	1.0×10^{12}
Hysol PC16	Epoxy	5	0.003	8.0×10^{11}
		6	0.003	1.0×10^{12}
		7	0.003	1.0×10^{12}
Dow Corning Q92-009	Silicone	11	0.003	7.0×10^{11}
		12	0.004	1.5×10^{12}
		13	0.003	7.0×10^{11}
Magnolia Plastics Magnobond 39	Epoxy-polysulfide	14	0.004	3.0×10^{11}
		15	0.004	3.0×10^{11}
		16	0.003	4.0×10^{11}
General Electric SS4090	Silicone	29	0.005	4.0×10^{11}
		30	0.007	3.0×10^{11}
		31	0.007	1.0×10^{11}

TABLE XIX (Cont)

Material Designation	Type	Test Board Number	Coating Thickness (Inches)	Resistance (Ohms)
Martin Emissivity Coating [1]	Acrylic	20	0.003	3.0×10^{11}
		21	0.003	2.0×10^{11}
		22	0.003	2.4×10^{11}
Uralane 5712	Poly-urethane	17	0.014	2.4×10^{10}
		18	0.015	2.8×10^{10}
		19	0.015	2.2×10^{10}
Hysol PC22	Poly-urethane	2	0.014	1.5×10^{10}
		3	0.013	2.0×10^{10}
		4	0.015	1.0×10^{10}
Products Research PR1538	Poly-urethane	26	0.010	1.4×10^{10}
		27	0.013	1.5×10^{10}
		28	0.015	1.0×10^{10}
Minnesota Mining and Manufacturing 3M280	Epoxy	23	0.003	8.0×10^{11}
		24	0.003	2.0×10^{9}
		25	0.003	8.0×10^{10}
Control		32	none	1.0×10^{12}
		33	none	7.0×10^{11}
		34	none	5.0×10^{11}

(1) Martin Preparation

3. Vibration

The printed circuit cards with inactive electronic components were subjected to a random vibration test as follows:

Frequency	Severity
100 cps to 1,000 cps	$1.0g^2/cps$
1,000 cps to 2,000 cps	6 db roll off
50 cps to 100 cps	6 db roll off

The root mean square value of the vibration spectrum is 38.5g. Figure 10 shows the test items mounted on the test fixture, which in turn is bolted to the C210 vibration head. The items were vibrated for 3 minutes in each of the three axis. The boards were subsequently observed to determine if the vibration caused any of the parts to shake loose.

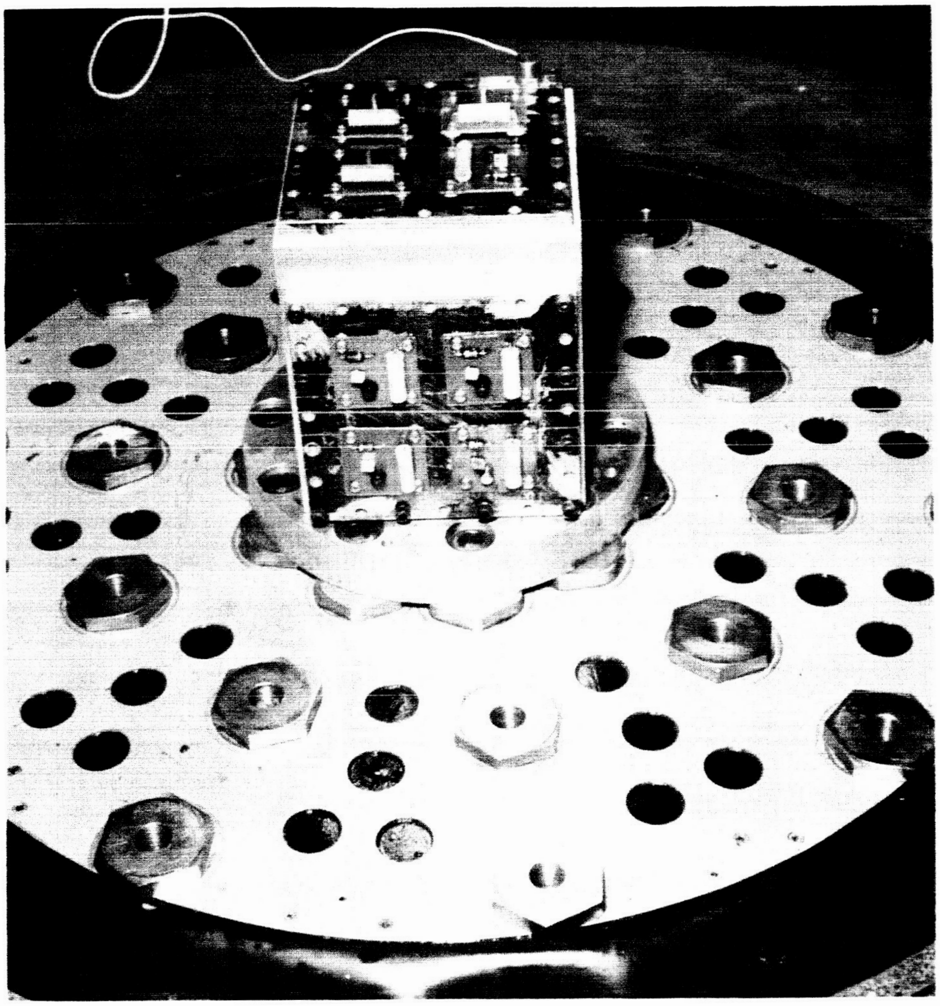


Figure 10. Printed Circuit Boards in Vibration Test Machine

This test was performed on the boards before they were subjected to any of the other enviroments and the test was repeated again after all the other environment tests had been performed.

The first vibration test caused a wire on two of the uncoated control boards to partially open at the solder joint. All coated boards successfully passed without any indication of failure. The second or post environmental test caused the rupture of two wires and the partial failure of a solder joint on the three uncoated control boards (Figure 9). However, no failures were noted on the coated boards. Thus, all coated boards performed satisfactorily during these two tests and gave tangible evidence that the coatings acted as protective mechanisms in preventing physical failure of the solder connections.

4. High Temperature

All boards were subjected to a high temperature test in the 5 x 4 x 2 1/2 foot hot pack chamber. This chamber is equipped with a circular chart temperature recorder. The test time duration was 100 hours and the steady state temperature was 250°F. At the end of 48, 72, and 96 hours respectively, the comb pattern boards were removed one at a time from the chamber and resistance measurements made about 30 seconds after removal from the chamber. Resistance readings appear in Table XX.

All coatings showed a decrease in resistance of about one to three orders of magnitude. After being removed from high temperature, the resistances returned to approximately their former values. The performance of the two silicone compounds was superior to that of the other coatings. In general, the epoxies performed next best with the polyurethanes being ranked at the bottom of the list.

5. Low Temperature

All boards were subjected to a low temperature test in the Webber 4 x 4 x 4 foot low temperature chamber. This chamber was equipped with a continuous, strip chart recorder. Resistance measurements were made by fastening the comb pattern boards to a piece of plywood and monitoring while the boards were in the low temperature environment (Figure 11). The test duration was 48 hours at a temperature of -65°F. Resistance measurements were noted and appear in Table XXI.

Almost all of the boards showed an increase in resistance at low temperature over that experienced at ambient temperature. However, the low temperature environment had little permanent effect on resistance readings, and all coatings were considered satisfactory for use under comparable conditions.

6. Temperature Shock

The comb pattern boards and the printed circuit boards with inactive components were subjected to a temperature shock test similar to that specified by MIL-E-5272, with the exception that the high temperature limit was 185°F and the low temperature was -40°F. The boards were held at each temperature extreme for one hour with transfers from one temperature to the other being accomplished in less than five minutes. Three cycles of temperature shock were performed. The comb pattern boards were given a resistance check before starting this test and again at the completion, while the boards were at ambient. Results of the tests are shown in Table XXII.

TABLE XX

Effect of Elevated Temperature on Coatings

Material Designation	Type	Test Board No.	Resistance After 48 Hours (ohms)	Remarks	Resistance After 72 Hours (ohms)	Remarks	Resistance After 96 Hours (ohms)	Remarks	Post Hi Temp Resistance (ohms)
GE SS4090	Silicone	29	2.0×10^{10}	No discoloration	2.0×10^{11}	No discoloration	2.2×10^{11}	No discoloration	8.0×10^{11}
		30	3.0×10^{10}	No discoloration	2.0×10^{11}	No discoloration	1.0×10^{11}	No discoloration	1.0×10^{12}
		31	5.0×10^{10}	Slightly discolored	7.0×10^{10}	Slightly discolored	1.6×10^{11}	Slightly discolored	6.0×10^{11}
Martin Emissivity Coating	Acrylic	20	1.6×10^{9}		5.0×10^{10}		5.0×10^{10}		1.0×10^{12}
		21	8.0×10^{8}		3.0×10^{10}		4.0×10^{11}		1.0×10^{12}
		22	8.0×10^{8}		3.0×10^{10}		1.4×10^{10}		9.0×10^{11}
3M280	Epoxy	23	3.0×10^{9}		5.0×10^{10}		7.0×10^{10}		1.5×10^{12}
		24	4.0×10^{9}		5.0×10^{10}		5.0×10^{10}		1.0×10^{12}
		25	6.0×10^{9}		2.0×10^{11}		8.0×10^{10}		9.0×10^{11}
PC Q92-009	Silicone	11	8.0×10^{10}		2.0×10^{11}		1.0×10^{10}		1.0×10^{12}
		12	8.0×10^{10}		3.0×10^{11}		2.0×10^{10}		1.0×10^{12}
		13	5.0×10^{9}		2.0×10^{10}		1.0×10^{10}		1.0×10^{12}
Hysol PC16	Epoxy	5	2.0×10^{10}		2.0×10^{10}		4.0×10^{8}		2.0×10^{12}
		6	4.0×10^{10}		1.0×10^{10}		1.0×10^{10}		2.0×10^{12}
		7	5.0×10^{10}		5.0×10^{9}		1.0×10^{10}		1.0×10^{12}
Magnobond 39	Epoxy-Poly-sulfide	14	4.0×10^{8}		1.0×10^{10}		1.0×10^{9}		2.0×10^{12}
		15	4.5×10^{8}		2.0×10^{11}		7.0×10^{9}		6.0×10^{11}
		16	3.0×10^{8}		3.0×10^{10}		9.0×10^{8}		7.0×10^{11}
Humiseal 1A27	Poly-urethane	8	1.0×10^{11}		1.0×10^{10}		1.0×10^{9}		1.0×10^{12}
		9	8.0×10^{10}		1.0×10^{10}		1.0×10^{9}		1.0×10^{12}
		10	5.0×10^{10}	Slightly discolored	2.0×10^{10}	Slightly discolored	9.0×10^{8}	Slightly discolored	1.0×10^{12}
Products Research PR1538	Poly-urethane	26	1.6×10^{8}	Tacky	7.0×10^{8}	Tacky	2.6×10^{8}	Tacky	4.0×10^{9}
		27	9.0×10^{7}	Tacky	4.5×10^{8}	Tacky	2.4×10^{8}	Tacky	3.4×10^{9}
		28	2.4×10^{8}	Tacky	5.0×10^{8}	Tacky	2.4×10^{8}	Tacky	3.6×10^{9}
Uralane 5712	Poly-urethane	17	1.0×10^{8}	Slightly discolored	9.0×10^{8}	Slightly discolored	4.0×10^{8}	Slightly discolored	1.4×10^{10}
		18	4.0×10^{7}	Slightly discolored	3.0×10^{8}	Slightly discolored	8.0×10^{7}	Slightly discolored	1.6×10^{10}
		19	3.0×10^{7}	Slightly discolored	2.0×10^{8}	Slightly discolored	5.0×10^{7}	Slightly discolored	8.0×10^{9}
Hysol PC22	Poly-urethane	2	4.0×10^{7}	Slightly discolored	4.0×10^{7}	Slightly discolored	3.0×10^{8}	Slightly discolored	1.2×10^{9}
		3	4.0×10^{7}	Slightly discolored	4.0×10^{7}	Slightly discolored	2.0×10^{7}	Slightly discolored	1.4×10^{9}
		4	9.0×10^{7}	Slightly discolored	4.0×10^{7}	Slightly discolored	6.0×10^{7}	Slightly discolored	1.0×10^{9}
Control		32	6.0×10^{10}	Control	1.0×10^{12}	Control	1.0×10^{11}	Control	1.0×10^{12}
		33	5.0×10^{10}	Control	1.0×10^{12}	Control	3.8×10^{11}	Control	1.0×10^{12}
		34	3.0×10^{10}	Control	7.0×10^{11}	Control	9.0×10^{11}	Control	9.0×10^{11}

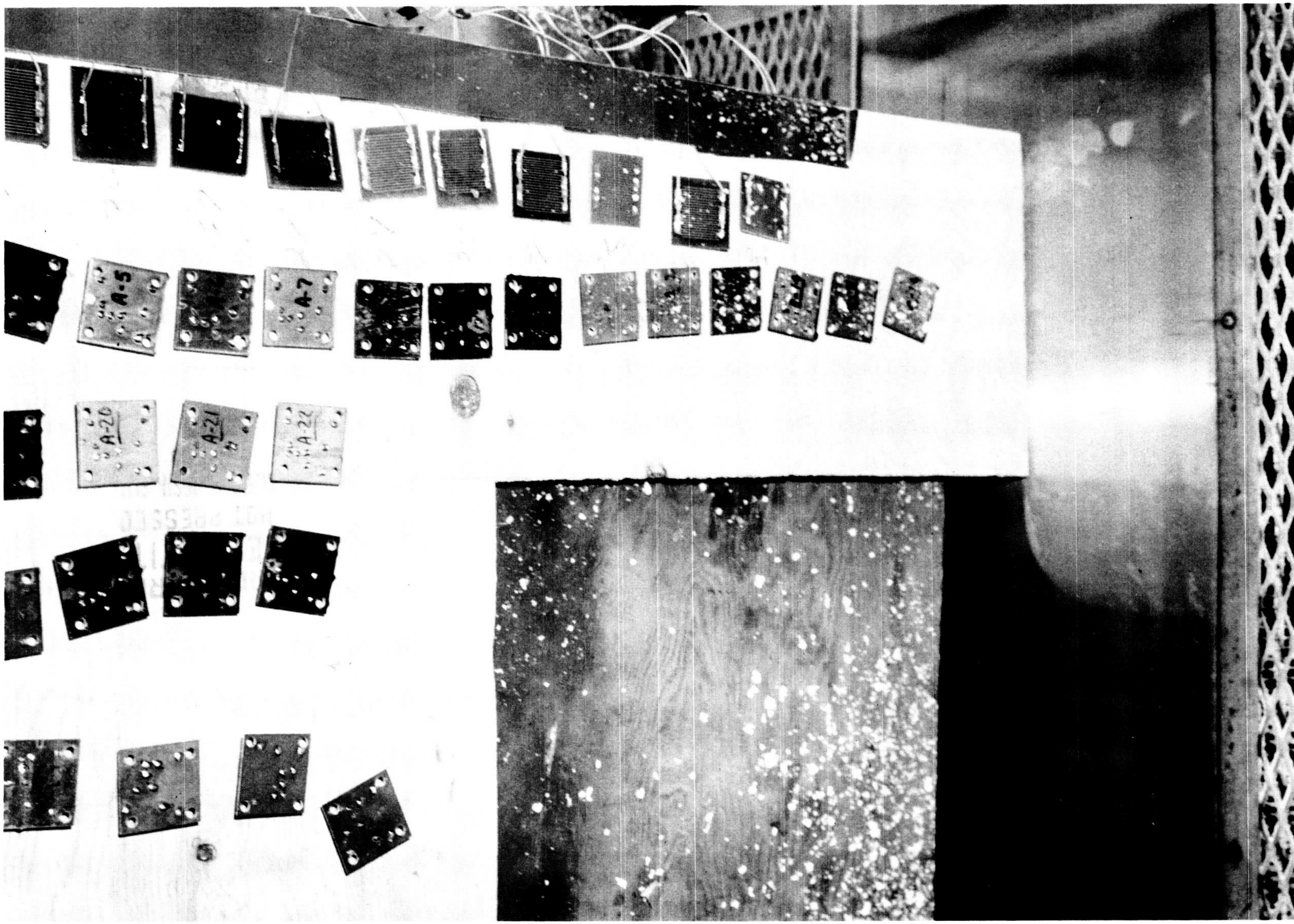


Figure 11. Circuit Boards Used in Low Temperature Tests

TABLE XXI

Effect of Low Temperature on Coatings

Material Designation	Type	Test Board No.	Pre-Low Temperature Resistance Reading (ohms)	Low Temp (after 48 hrs environment) Resistance Reading (ohms)	Post Low Temperature Resistance Reading (ohms)
Hysol PC16	Epoxy	5	$2x10^{12}$	$1x10^{12}$ or greater	$1.5x10^{12}$
		6	$2x10^{12}$		$2x10^{12}$
		7	$1x10^{12}$		$2x10^{12}$
Dow Corning Q 92-009	Silicone	11	$1x10^{12}$		$1x10^{12}$
		12	$1x10^{12}$		$1.5x10^{12}$
		13	$1x10^{12}$		$1x10^{12}$
Magnobond 39	Epoxy-polysulfide	14	$2x10^{12}$		$1.5x10^{12}$
		15	$6x10^{11}$		$1x10^{12}$
		16	$7x10^{11}$		$1x10^{12}$
Humiseal 1A27	Poly-urethane	8	$1x10^{12}$		$1x10^{12}$
		9	$1x10^{12}$		$1x10^{12}$
		10	$1x10^{12}$		$1x10^{12}$
Martin Emissivity Coating (1)	Acrylic	20	$1x10^{12}$		$1x10^{12}$
		21	$1x10^{12}$		$1x10^{12}$
		22	$9x10^{11}$		$1x10^{12}$
GE SS4090	Silicone	29	$8x10^{11}$		$9x10^{11}$
		30	$1x10^{12}$		$2x10^{12}$
		31	$6x10^{11}$		$1.5x10^{12}$
3M280	Epoxy	23	$1.5x10^{12}$		$1x10^{12}$
		24	$1x10^{12}$		$3.5x10^{10}$
		25	$9x10^{11}$		$9x10^{11}$
Uralane 5712	Poly-urethane	17	$1.4x10^{10}$		$1x10^{10}$
		18	$1.6x10^{10}$		$6x10^{9}$
		19	$8x10^{9}$		$7x10^{9}$
Products Research PR 1538	Poly-urethane	26	$4x10^{9}$		$4.5x10^{9}$
		27	$3.4x10^{9}$		$3.6x10^{9}$
		28	$3.6x10^{9}$		$3.3x10^{9}$
Hysol PC22	Poly-urethane	2	$1.2x10^{9}$		$8x10^{8}$
		3	$1.4x10^{9}$		$9x10^{8}$
		4	$1x10^{9}$		$7x10^{8}$
Control		32	$1x10^{12}$		$1.8x10^{11}$
		33	$1x10^{12}$		$8x10^{11}$
		34	$9x10^{11}$	$1x10^{12}$ or greater	$1x10^{12}$

(1) Martin Preparation

TABLE XXII

Effect of Temperature Shock on Coatings

Pre-Temperature Shock				Post Temperature Shock	
Material Designation	Type	Test Board No.	Resistance Reading (ohms)	Resistance Reading (ohms)	Remarks
GE SS4090	Silicone	29	$9x10^{11}$	$2x10^{12}$	Small bubbles
		30	$2x10^{12}$	$2x10^{12}$	
		31	$1.5x10^{12}$	$2x10^{12}$	
Hysol PC16	Epoxy	5	$1.5x10^{12}$	$2x10^{12}$	Small bubbles under coating
		6	$2x10^{12}$	$2x10^{12}$	
		7	$2x10^{12}$	$2x10^{12}$	
Magnobond 39	Epoxy-Polysulfide	14	$1.5x10^{12}$	$2x10^{12}$	Small bubbles
		15	$1x10^{12}$	$2x10^{12}$	
		16	$1x10^{12}$	$2x10^{12}$	
Humiseal 1A27	Poly-urethane	8	$1x10^{12}$	$2x10^{12}$	
		9	$1x10^{12}$	$2x10^{12}$	
		10	$1x10^{12}$	$1.5x10^{12}$	
Dow Corning Q 92-009	Silicone	11	$1x10^{12}$	$2x10^{12}$	Small bubbles under coating
		12	$1.5x10^{12}$	$2x10^{12}$	
		13	$1x10^{12}$	$1.5x10^{12}$	
Martin Emissivity Coating (1)	Acrylic	20	$1x10^{12}$	$2x10^{12}$	
		21	$1x10^{12}$	$2x10^{12}$	
		22	$1x10^{12}$	$1.5x10^{12}$	
3M280	Epoxy	23	$1x10^{12}$	$2x10^{12}$	
		24	$3.5x10^{12}$	$4.5x10^{10}$	
		25	$9x10^{11}$	$2.0x10^{12}$	
Uralane 5712	Poly-urethane	17	$1x10^{10}$	$4x10^{10}$	Small bubbles
		18	$6x10^{9}$	$4x10^{10}$	Small bubbles
		19	$7x10^{9}$	$2.2x10^{10}$	
Products Research 1538	Poly-urethane	26	$4.5x10^{9}$	$7x10^{9}$	
		27	$3.6x10^{9}$	$5x10^{9}$	
		28	$3.3x10^{9}$	$5x10^{9}$	
Hysol PC22	Poly-urethane	2	$8x10^{8}$	$1.5x10^{9}$	
		3	$9x10^{8}$	$1.8x10^{9}$	
		4	$7x10^{8}$	$1x10^{9}$	
Control		32	$1.8x10^{11}$	$1x10^{11}$	
		33	$8x10^{11}$	$4x10^{11}$	
		34	$1x10^{12}$	$2x10^{12}$	

(1) Martin Preparation

With the exception of the Hysol PC22 coated boards number 2, 3, and 4, the temperature shock test appeared to have a negligible effect on the electrical properties of the boards. Some of the coatings developed small bubbles during this temperature cycling. Although these bubbles had no apparent effect on the electrical properties, they are not desirable.

7. Humidity

All of the printed circuit boards were subjected to a ten day humidity test as specified in MIL-STD-202, Method 106B, Figure 106-1, except that no power was applied during the test and the vibration portion was eliminated. Prior to test initiation, a resistance measurement of the comb pattern boards was made under ambient conditions. Near the end of the first, third and tenth test cycle, the boards were removed from the chamber, five at a time. The leads were wiped clean of moisture and resistance measurements made. The printed circuit boards with inactive electronic components were visually inspected at the end of the tenth cycle. Resistance measurement results appear in Table XXIII.

As would normally be expected, a slight general decrease was noted in the test board resistances as a result of exposure to humidity. However, since no significant resistance changes were noted from one type of compound to the other, all compounds listed are considered as possessing equal qualities relative to withstanding the effects of humidity.

8. Fungus

To determine if materials would support fungus, two printed circuit boards for each type of coating material tested were subjected to a 28 day fungus test in accordance with MIL-STD-E5272C. No electrical checks were made before or after test initiation. At the conclusion of the 28 day period, the boards were visually inspected to determine the effects of the test environment. Figure 12 shows the specimens at the end of the 28 day period. The complete absence of fungus growth on the test boards is apparent. However, the wood support structure as well as the control located in the circular dish show strong indications of fungus support. Of the compounds tested, none presented any evidence relative to the support of fungus.

TABLE XXIII

Effect of Humidity on Coatings

Material Designation	Type	Test Board No.	Pre-Humidity	End of 1st Cycle	End of 3rd Cycle	End of 10th Cycle
Humiseal 1A27	Poly-urethane	8	7×10^{11}	7×10^{10}	5×10^{10}	8×10^{10}
		9	6×10^{11}	2×10^{11}	8×10^{8}(2)	1×10^{11}
		10	3.2×10^{11}	5×10^{10}	2.1×10^{9}	5×10^{10}
Magnobond 39	Epoxy-polysulfide	14	4×10^{11}	8×10^{10}	4.5×10^{10}	1×10^{11}
		15	5×10^{11}	1.6×10^{11}	4×10^{10}	4×10^{10}
		16	4×10^{11}	1.6×10^{11}	2.8×10^{10}	4×10^{10}
GE SS4090	Silicone	29	5×10^{11}	2×10^{11}	4.5×10^{9}	3×10^{10}
		30	7×10^{11}	2.4×10^{11}	7×10^{9}	1×10^{11}
		31	3×10^{11}	8×10^{10}	1×10^{10}	4×10^{10}
Dow Corning Q92-009	Silicone	11	4×10^{11}	1.8×10^{11}	3.7×10^{10}	8×10^{10}
		12	3×10^{11}	1.2×10^{11}	3.2×10^{10}	7×10^{10}
		13	2×10^{11}	1×10^{11}	7.5×10^{9}	8×10^{10}
Hysol PC16	Epoxy	5	3×10^{11}	1.2×10^{11}	8×10^{9}	6×10^{10}
		6	4×10^{11}	9×10^{10}	4×10^{10}	7×10^{10}
		7	5×10^{11}	1.6×10^{10}	1×10^{11}	7×10^{10}
3M280	Epoxy	23	4×10^{11}	1.2×10^{11}	3.6×10^{10}	7×10^{10}
		24	5×10^{7}	7×10^{7}	2.4×10^{8}	7×10^{9}
		25	1.6×10^{9}	7×10^{8}	3.6×10^{8}	3×10^{9}
Uralane 5712	Poly-urethane	17	3.6×10^{9}	1×10^{9}	1.6×10^{9}	3×10^{8}
		18	3.6×10^{9}	1×10^{9}	2.4×10^{9}	4×10^{8}
		19	3×10^{9}	1×10^{9}	1.8×10^{9}	5×10^{8}
Martin Emissivity Coating(1)	Acrylic	20	4×10^{11}	5×10^{9}	5×10^{9}	6×10^{8}
		21	5×10^{11}	3×10^{9}	7×10^{9}	1.4×10^{9}
		22	4×10^{8}	8×10^{8}	4.5×10^{9}	3×10^{7}
Product Research PR1538	Poly-urethane	26	1×10^{9}	3×10^{8}	8×10^{8}	1×10^{8}
		27	7×10^{8}	2×10^{8}	4×10^{8}	3×10^{7}
		28	8×10^{8}	2.6×10^{8}	6×10^{8}	1×10^{8}
Hysol PC22	Poly-urethane	2	3.6×10^{8}	1.6×10^{8}	4×10^{8}	8×10^{7}
		3	4.5×10^{8}	1.6×10^{8}	4.5×10^{8}	6×10^{7}
		4	3.6×10^{8}	1×10^{8}	3.2×10^{8}	4×10^{7}
Control		32	1.6×10^{9}	2×10^{7}	8×10^{9}	1×10^{10}
		33	5×10^{9}	4×10^{10}	1.8×10^{10}	3×10^{10}
		34	1.6×10^{9}	4×10^{10}	2.8×10^{10}	6×10^{10}

(1) Martin Preparation

(2) Reading suspected as being in error

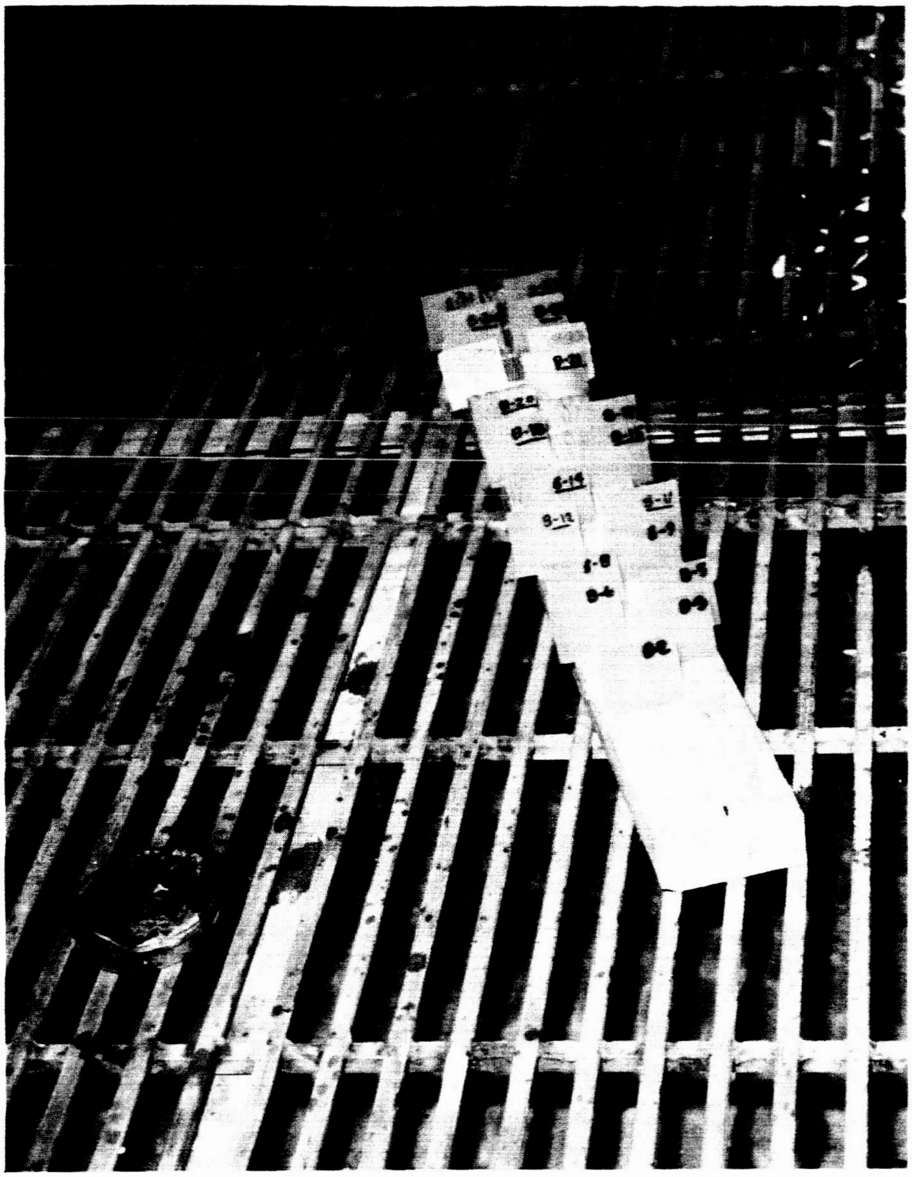


Figure 12. Printed Circuit Boards at the End of a 28 Day Fungus Test

IV. MOST PROMISING COATINGS

The completion of the environmental test study concluded the test phase relative to the selection of one or more high emissivity conformal coatings suitable for use in electrical/electronic applications. At this stage of the program, seven of the most promising compounds were selected through an evaluation of the test results, and absolute emissivity values of these coatings determined. Table XXIV gives these coatings and the emissivity.

TABLE XXIV

Absolute Values of Emissivity of Selected Coatings

Material Designation	Type	Black Body Reference Temperatures		
		95°F 35°C	131°F 55°C	167°F 75°C
Hysol PC16	Epoxy	.974	.959	.958
Humiseal 1A27	Polyurethane	.941	.956	.971[1]
Magnobond 39	Epoxy-Polysulfide	.963	.953	.951
DC Q92-009	Silicone	.960	.951	.943
Products Research PR1538	Polyurethane	.969	.947	.942
Uralane 5712	Polyurethane	.958	.942	.936
GE SS4090	Silicone	.944	.900	<.900
Black Body Reference		.990	.990	.990

[1] No readily apparent reason for the reversal of emissivity value with rise in temperature for this coating was noted.

For these emissivity measurements, the coated aluminum squares, previously used for the relative measurements, were placed individually on a platen. Then the temperature of the plates was adjusted until the radiation level was equal to that of a calibrated black body at a specific temperature. Since the reference black body has an emissivity between 0.98 and 1.00, a value of 0.99 was assumed in calculating emissivity as follows:

$$w = e \sigma T^4$$

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where

w = total radiant flux per unit area
e = emissivity factor
σ = Stefan-Boltzman constant
T = absolute temperature (°K)

let

e_1 = emissivity factor of the coating

e_2 = 0.99 = emissivity factor of the black body

T_1 = temperature of the platen

T_2 = temperature of the black body

w_1 = total radiant flux per unit area of coating

w_2 = total radiant flux per unit area of black body.

Then $w_1 = w_2$ since the field of view of the radiometer is fixed and the outputs adjusted to be equal

$$e_1 \sigma T_1^4 = e_2 \sigma T_2^4$$

σ is constant and may be eliminated, e_2 equals 0.99: Thus

$$e_1 = \frac{0.99\, T_2^4}{T_1^4}$$

V. CONCLUSIONS

A study of the tables presenting the test data shows that most of the ten final compounds performed satisfactorily as high emissivity transparent conformal coatings. Some of the test results listed in the tables are composed of more than one factor, such as curing cycle data, solderability, chemical resistance, and electrical properties. Therefore interpretation of these results is subject to variance, being dependent on the end performance desired.

The only specific areas of appreciable weakness that were noted were as follows: 1) adhesion – two coatings, Minnesota Mining and Manufacturing 3M280 and Humiseal 1A27, parted from the test board at a relatively low value, failing at the critical coating/circuit board interface; 2) water absorption – one coating, Hysol PC 22, absorbed an appreciable amount of water (1.4 percent); 3) elevated temperature electrical properties – two coatings, Martin emissivity coating and Humiseal 1A27, softened excessively at the 200°F test temperature; 4) outgassing – one coating, General Electric SS4090, a solvent containing system, outgassed to the extent of losing over 5 percent of its weight. However, in actual usage as a conformal coating, a much thinner film of material would be involved than that used in the outgassing test. This would allow a more complete escape of solvent during cure, therefore reducing the outgassing tendencies of the coating.

In Table XXV, each of the ten final coating compounds have been ranked according to their performance on each of the properties as determined during the test program. This table provides a ready reference and permits the rapid selection of a coating to be made for use in any one of a number of environments.

TABLE XXV

Rating of Most Promising Coatings

Desired Property	Order of Performance									
	1	2	3	4	5	6	7	8	9	10
Emissivity(1)	MEC(2)	PC16	1A27	M-39(3)	Q92-009	PR1538	UR5712(4)	SS4090	PC22(5)	3M280(5)
Curing Cycle	MEC	1A27	Q92-009	PC16	M-39	PR1538	SS4090	3M280	PC22	UR5712
Flexibility	Q92-009	SS4090	PC22	PR1538	UR5712	M-39	MEC	1A27	PC16	3M280
Adhesion	PC16	PC22	M-39	PR1538	UR5712	Q92-009	SS4090	MEC	3M280	1A27
Water Absorption	SS4090	3M280	Q92-009	UR5712	1A27	PR1538	M-39	PC16	MEC	PC22
Linear Thermal Expansion	PC16	3M280	UR5712	PR1538	PC22	Q92-009(6)	SS4090(6)	M-39(6)	MEC(6)	1A27(6)
Solderability	SS4090	Q92-009	PC16	3M280	PC22	UR5712	PR1538	MEC	M-39	1A27
Chemical Resistance	M-39	Q92-009	PC22	UR5712	PC16	SS4090	3M280	PR1538	MEC	1A27
Electrical Properties										
Dielectric Constant (RT)(7)	MEC	SS4090	1A27	Q92-009	3M280	PC16	PR1538	UR5712	PC22	M-39
(Hi)(8)	SS4090	Q92-009	3M280	UR5712	PR1538	PC22	M-39	PC16	1A27	MEC
Dissipation Factor (RT)	SS4090	Q92-009	1A27	3M280	PC16	M-39	PR1538	UR5712	PC22	MEC
(Hi)	Q92-009	SS4090	3M280	UR5712	PC22	PR1538	PC16	M-39	1A27	MEC
Surface Resistivity (RT)	M-39	3M280	UR5712	PC16	SS4090	MEC	Q92-009	PR1538	PC22	1A27
(Hi)	SS4090	3M280	Q92-009	PR1538	M-39	UR5712	PC16	PC22	1A27	MEC
Volume Resistivity (RT)	Q92-009	1A27	3M280	PC16	UR5712	M-39	MEC	SS4090	PR1538	PC22
(Hi)	Q92-009	SS4090	3M280	UR5712	PR1538	PC16	PC22	M-39	1A27	MEC
Outgassing at 10^{-6} mm Hg	PC16	3M280	PC22	1A27	M-39	PR1538	Q92-009	UR5712	MEC	SS4090
Environmental Tests										
Hi Temperature Resistance	SS4090	MEC	3M280	Q92-009	PC16	M-39	1A27	PR1538	UR5712	PC22
Low Temperature Resistance	PC16	Q92-009	M-39	1A27	MEC	SS4090	3M280	UR5712	PR1538	PC22
Temperature Shock	SS4090	PC16	M-39	1A27	Q92-009	MEC	3M280	UR5712	PR1538	PC22
Humidity Resistance	1A27	M-39	SS4090	Q92-009	PC16	3M280	UR5712	MEC	PR1538	PC22

(1) Absolute, except as noted
(2) Martin Emissivity Coating
(3) Magnobond 39
(4) Uralane 5712
(5) Relative emissivity value ranking
(6) Expansion not determined. Compounds assigned equal performance
(7) Room temperature
(8) at 200°F

VI. RECOMMENDATIONS

The coatings were not evaluated with any particular usage environment specified. Therefore no one material can be recommended as being superior to the others, for no one material was outstanding in all test areas. For example, a study of the complete test data shows that Dow Corning Q92-009 silicone material performed above average. This material can be especially recommended for elevated temperature, high humidity environments. Hysol PC16 epoxy also exhibited highly satisfactory characteristics in many test areas. This material had the highest absolute emissivity of those compounds measured (see Table XXIV). This material is therefore recommended for general environmental usage and when high emissivity is required in standardizing thermal measurements. General Electric SS4090 silicone performed above average in areas such as flexibility, water absorption, and elevated temperatue properties. It was less satisfactory with respect to outgassing and emissivity. The compound is therefore recommended for use in elevated temperature, high humidity environments requiring only fair emissivity and limited resistance to outgassing.

The test program conducted as planned, did not include a study of the following areas:

1 Do different lots of the same material have comparable emissivities?

2 What is the effect of aging in various environments on emissivity?

Further effort to include a study of these points is recommended.

VII. FUTURE PLANS

The remaining work under Contract NAS 8-20131 consists of completing Phase III activities. Approximately 45 percent of Phase III has been completed to date and the following will be completed by the end of the contract.

1. Completing life tests on various groupings of transistors to determine the feasibility of correlating infrared radiation and life expectancy of electrical/electronic devices.

2. "Fingerprinting" circuit assemblies to determine the feasibility of using infrared in evaluating thermal design in packaging techniques. The evaluation of thermal design in packaging will include tests on three elements of packaging: heat sink design, component mounting on heat sinks, and component density on circuit boards.

3. Preparing a specification adequate for the procurement of a radiometer, associated fixtures, and equipment.

Monthly progress reports will be issued in addition to a comprehensive final report.